



PHD

## International Climate Change Agreements and Linkages with Trade Policies

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# **International Climate Change Agreements and Linkages with Trade Policies**

Alaa Al Khourdajie

A thesis submitted for the degree of Doctor of Philosophy

University of Bath

Department of Economics

August 2017

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# Table of Contents

## Contents

<b>I</b>	<b>Acknowledgments</b>	<b>9</b>
<b>II</b>	<b>Thesis Format Structure</b>	<b>11</b>
<b>III</b>	<b>Thesis Abstract</b>	<b>13</b>
<b>IV</b>	<b>Introduction Chapter</b>	<b>15</b>
<b>V</b>	<b>Paper 1: Strategic Environmental Policy, International Trade and Self-enforcing Agreements: The Role of Consumers' Taste for Variety</b>	<b>22</b>
<b>1</b>	<b>Introduction</b>	<b>25</b>
<b>2</b>	<b>Model</b>	<b>27</b>
2.1	Payoff Function . . . . .	27
2.2	Coalition Formation Game . . . . .	29
2.3	Properties of the Game . . . . .	30
<b>3</b>	<b>Results</b>	<b>30</b>
3.1	Third Stage . . . . .	30
3.2	Second Stage . . . . .	33
3.3	Properties of the Coalition Game . . . . .	37
3.4	First Stage . . . . .	39
<b>4</b>	<b>Concluding Remarks</b>	<b>40</b>
<b>5</b>	<b>References</b>	<b>42</b>

<b>6</b>	<b>Appendixes</b>	<b>44</b>
6.1	Equilibrium Taxes for all Scenarios . . . . .	44
6.2	Definitions . . . . .	45
6.3	Non-negativity Constraints . . . . .	46
6.4	Proposition 2 - Comparing Equilibrium Taxes Across Different Welfare Scenarios . . . . .	48
6.5	Proposition 3 - Comparing Equilibrium Taxes within each Welfare Scenario . . . . .	49
6.6	Proposition 4 - Properties of the Coalition Game . . . . .	51
6.7	Proposition 5 - Coalition Stability . . . . .	54
<b>VI</b>	<b>Paper 2: Measures to Enhance the Effectiveness of International Climate Agreements: The Case of Border Tax Adjustments</b>	<b>56</b>
<b>1</b>	<b>Introduction</b>	<b>59</b>
<b>2</b>	<b>Model</b>	<b>62</b>
2.1	Payoff Function . . . . .	62
2.2	Coalition Formation Game . . . . .	66
2.3	Properties of the Game . . . . .	66
<b>3</b>	<b>Results</b>	<b>68</b>
3.1	Third Stage . . . . .	68
3.2	Second Stage . . . . .	73
3.3	First Stage . . . . .	75
<b>4</b>	<b>Concluding Remarks</b>	<b>80</b>
<b>5</b>	<b>References</b>	<b>82</b>
<b>6</b>	<b>Appendixes</b>	<b>84</b>
6.1	Appendix 1: Properties of the Game . . . . .	84
6.2	Appendix 2: Equilibrium Quantities Derivations . . . . .	86
6.2.1	BTA Regime . . . . .	86

6.2.2	No BTA Regime . . . . .	88
6.3	Appendix 3: Equilibrium Taxes . . . . .	90
6.3.1	No BTA Regime Equilibrium Taxes . . . . .	90
6.3.2	BTA Regime Equilibrium Taxes . . . . .	91
6.4	Appendix 4: Parameters Constellations . . . . .	91
6.4.1	Non-negativity Constraints . . . . .	91
6.4.2	BTA Constraints . . . . .	92
6.4.3	Parameters' Space . . . . .	92
6.4.4	Analysis Strategy . . . . .	93
6.5	Appendix 5: Non-negativity Constraints for the No BTA Scenario . .	94
6.6	Appendix 6: Detailed Results . . . . .	96

## **VII Paper 3: Joint Climate Change and Customs' Union Agreements under Consumers' Taste for Variety 104**

<b>1</b>	<b>Introduction</b>	<b>107</b>
<b>2</b>	<b>Model</b>	<b>111</b>
2.1	Payoff Function . . . . .	111
2.2	Coalition Formation Game . . . . .	113
2.3	Choices of Policy . . . . .	114
2.4	Properties of the Game . . . . .	115
<b>3</b>	<b>Results</b>	<b>116</b>
3.1	Third Stage . . . . .	116
3.2	Second Stage . . . . .	121
3.3	First Stage Results . . . . .	125
3.4	Further Simulations . . . . .	131
<b>4</b>	<b>Concluding Remarks</b>	<b>132</b>
<b>5</b>	<b>References</b>	<b>135</b>

<b>6</b>	<b>Appendixes</b>	<b>137</b>
6.1	Appendix 1: Equilibrium Quantities Derivations . . . . .	137
6.1.1	Signatories' Markets . . . . .	137
6.1.2	Non-signatories' Markets . . . . .	141
6.2	Appendix 2: Equilibrium Emission Taxes and Trade Tariffs . . . . .	142
6.3	Appendix 3: Non-negativity Constraints . . . . .	143
6.3.1	Environmental Cooperation scenario . . . . .	143
6.3.2	Trade Cooperation scenario . . . . .	143
6.3.3	Joint Cooperation scenario . . . . .	144
6.4	Appendix 4: First Stage Results . . . . .	144
<b>VIII</b>	<b>Summary of Conclusions</b>	<b>146</b>

*To my mother, Wafaa Al Zayed (1952-2015),  
who instilled in me the invaluable traits of determination and perseverance which  
have got me this far in life*





## Part I

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*Alaa Al Khourdajie*

*August, 2017*



## Part II

# Thesis Format Structure

This thesis follows the newly introduced alternative format of “papers’ portfolio”. All papers are closely related in terms of the subject matter. Each paper includes a commentary in its introduction section that contextualises and integrates the paper into the research narrative of the thesis.



## Part III

# Thesis Abstract

In an  $n$ -country intra-industry trade model we study the formation and stability of various designs of climate change agreements in the context of international trade. In the first paper we introduce two new features to the literature. Firstly, firms produce a horizontally differentiated good, i.e. the same good but in different varieties where each firm produces one unique variety. Secondly, consumers can have various degrees of taste for the varieties of this good. Our results in this paper show that if consumers have a low taste for variety (TFV) agreement formation fails. Only with a sufficiently high TFV, strategic interaction among governments is sufficiently mitigated such that small agreements are stable.

In the second paper we analyse the effects of instrumenting climate change agreements with a trade policy called border tax adjustment (BTA) in order to assess its ability of mitigating the free riding incentives. Our results show that when varieties do not matter to consumers, BTAs lead to a global agreement on climate change if coalition membership is open to all countries. If membership is exclusive, then fewer countries form an agreement and do not allow other countries to join. When consumers have high TFV, large, but not global, agreements are stable.

In the third paper we analyse the case where governments have to deal with two issues: climate change and trade. We examine coalition formation and stability under three scenarios where governments are either cooperating on one issue only or on both issues at the same time. Our results show that whenever governments cooperate on trade, either individually or with climate change, the grand coalition is always stable. More interestingly, we find that when governments cooperate on climate change only the grand coalition is also stable. However, this holds only when varieties are perfect substitutes.



## Part IV

# Introduction Chapter

Global actions to effectively combat climate change require an unprecedented level of coordination among countries. This is due to the fact that greenhouse gases (GHGs), one of the major causes of global warming (Botzen, 2011), mix perfectly in the atmosphere making climate change a global common problem (Stavins et al., 2014). In the attempt to streamline such level of international coordination the United Nation Framework Convention on Climate Change (UNFCCC) was first adopted in 1992 at the Rio Earth Summit. The Convention’s ultimate objective is “stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system” (UNFCCC, 2017).

In order to put the Convention into practice, UNFCCC signatories are required to meet formally on annual basis and negotiate an international climate change treaty. One of the main achievements of these negotiations was Kyoto Protocol signed in 1997. In its first commitment period (2008-2012), Kyoto Protocol sets binding emission reduction targets for 37 industrialised countries. Overall, these targets add up to an average of five per cent emission reductions compared to 1990 levels, making them insufficient to achieve the UNFCCC objectives. Under its central principle of “common but differentiated responsibility”, Kyoto Protocol applies only to industrialised countries because it recognises their responsibilities for the current high levels of GHG emissions’ concentration in the atmosphere due to more than 100 years of industrial activities, (UN, 1998).

During this period, signatories of Kyoto Protocol failed to agree on extending the Protocol to a second commitment period for various reasons. Most notably was the exclusion of emerging and developing economies, such as China, who are increasingly becoming major contributors to global GHG emissions. Nevertheless, the annual negotiations were continued in order to reach an alternative global treaty and in December 2015 Paris Climate Agreement was signed by 197 countries. This agreement aims to achieve the scientifically recommended target of limiting the temperature increase by the year 2100 to 2 degrees Celsius compared to pre-industrial levels. In other words, this target is inline with the UNFCCC Convention. However, despite agreeing on this target, signatories’ current emission reduction pledges fall short of meeting it and will potentially yield a temperature increase of 2.7-3 degrees Celsius (UNFCCC, 2015). Furthermore, Paris Climate Agreement fails to bind its signatories to meet their pledges.

Scholars in the game theoretic literature on the formation of international environmental agreements (IEAs) attribute the difficulty in reaching an effective climate change agreement to strong free-riding incentives. These incentives emerge due to the fact that any non-signatory would enjoy the environmental benefits resulting



from signatories' emissions reduction efforts without incurring any costs. Therefore, given the absence of supranational authority that could enforce cooperation on climate change, any stable agreement has to be self-enforcing. Findings in this literature show that this free riding phenomenon has either led to agreements with few signatories and/or with very low and hence ineffective emission reduction targets. In other words, these agreements are either small, shallow or both (see Barrett, 1994; and Finus, 2003 for surveys).

In the context of international trade and free movement of goods and factors of production there are additional challenges for effective climate change actions. Unilateral or sub-global actions on climate change could lead to a shift in production towards non-signatory countries resulting in emission leakage. Furthermore, firms operating in signatory countries suffer from loss of competitiveness due to the costs of complying with the climate policy. In other words, when considering international trade, incentives for coordinating (free riding on) climate change actions are weaker (stronger) than the case of autarky. Check Zhang (2012) for a survey on the theoretic literature and empirical evidence.

In order to overcome such pessimistic predictions, further contributions in the game theoretic literature followed different strategies such as analysing various policy instruments, markets' structures or trade features. One approach that has been addressed in the literature when designing a treaty is sanctions used to deter free riding. An example of non-participation sanctions is in Montreal Protocol, where trading of the controlled substances with non-participants is banned (Montreal Protocol Article 4). Although sanctions might appeal as suitable measures for deterring free riding behaviour, in reality they face credibility, institutional and technical problems (Finus, 2002). Non-participation measures are at odd with the voluntary nature of the IEAs. Most importantly, implementing the sanctions is a time-consuming and costly process. Barrett (1997) finds that sanctions may harm not only non-signatories but also signatories. Finally, in a world with several multilateral agreements between countries, sanctions might destabilise or violate the terms of other agreements, such as those under the World Trade Organisation (Barrett, 2009).

Another approach is compensation measures. IEAs cooperation exhibits asymmetries in the welfare of the participants resulting in the instability of the agreement. In such case compensation measures could serve to balance these asymmetries. Finus (2003) classify compensation measures into monetary transfers and in-kind transfers such as technical and technological assistance. Although monetary transfers are more straightforward form of compensation measures in comparison to in-kind transfers, few IEAs have provisions for monetary transfers. There are four general arguments in the literature on the lack of the use of monetary transfers. Firstly, Mäler (1990) suggests that parties might hide their true preferences in order to extract higher compensation (commit to lower compensation) in the case of being payee (payer). Secondly, in the case where transfers are paid to non-participants for them to undertake some abatement efforts, Hoel and Schneider (1997) find that such form of

transfers may create adverse incentives for countries to join the agreement. Thirdly, Barrett (1994) argues that there might be some incentives for free-riding between the payers and the payees. For instance the payers are better off if the payee increases her abatement efforts without increasing the transfer. Furthermore, there are also internal free-riding incentives within the group of payers themselves. That is a payer might free-ride on her transfers' commitments, hoping that they will be fulfilled by other payers in the group. Finally, Finus (2002) suggests that there is a compliance problem where donors do not fulfill their promise or recipients do not meet the agreed abatement targets (depending on whether transfers are ex-post or ex-ante).

A third approach we mention briefly here is multiple coalitions. Carraro and Siniscalco (1998) show that grand coalitions are unlikely to exist and multiple coalitions tend to prevail. Botteon and Carraro (1997) show that even with the use of compensation mechanisms stability of grand coalitions require small degree of abatement commitments. Finus (2003) argues that small multiple agreements among different groups of countries on regional levels might achieve higher emission reductions than stable global agreement with low commitment targets. This is due to the fact that the degree of asymmetries on regional levels will be minimal. Furthermore, most regions across the world already cooperate on several agreements, such as on trade and defense, and hence the mechanisms for reaching consensus on the regional level are already in place and could facilitate a new agreement. This argument is also supported by Carraro's et al., (2007) concept of bottom-up approaches to climate policy.

In the attempt to provide policy makers with alternative designs of international agreements that may lead to a global and effective action on climate change, this thesis analyses the formation and stability of international climate change agreements under free trade and explores the effects of various policy instruments and trade features. Throughout the thesis, our model is an extension of Brander and Spencer (1985) framework with  $n$  *ex ante* symmetric countries. Governments can induce emission reductions from domestic production using emission taxes. Each government is concerned with the domestic firm's profit, revenues from emission taxes, the utility of the domestic consumers and the environmental damages resulting from a global pollutant. In this setting, we introduce three main contributions to the literature.

In the first paper (Finus and Al Khourdajie, 2017), we introduce two new features that are common in the trade literature but have not yet been explored in the IEAs literature. Firstly, firms produce a horizontally differentiated good, i.e. the same good but in different varieties where each firm produces one unique variety. Secondly, consumers have taste for the varieties of this differentiated good. Therefore, their utility depends not only on the total quantity consumed but also on the composition of quantities of the differentiated varieties. The combination of these two features allow for analysing IEAs under free trade when consumers' preferences matter. These features were introduced by Yi (1996 and 2000) to the trade agreements

literature and we benefit from his contribution. Our results in Finus and Al Khourdajie (2017) confirm the pessimistic conclusion which mainly emerges from the IEA literature. Agreements are small at best and may not exist at all due to strong free-rider incentives. If consumers have a low taste for variety, i.e. domestic and foreign varieties are viewed as good substitutes by consumers, agreement formation fails. Only with a sufficiently high taste for variety, strategic interaction of governments is sufficiently mitigated such that small agreements are stable.

In the second paper (Al Khourdajie et al., 2017), we extend Finus and Al Khourdajie (2017) and analyse the effects of instrumenting climate change agreements with a trade policy called border tax adjustment (BTA). Using this policy signatory governments can impose an additional border tax on imports from non-signatories' firms. This border tax amounts to the tax differential between the high emission tax that signatory firms are facing in their domestic markets and the low emission tax that non-signatory firms are facing for their exports to signatories' markets. Our results show that when varieties do not matter to consumers, BTAs lead to global agreement on climate change if membership is open to all countries. If membership is exclusive, then fewer countries form an agreement and do not allow other countries to join in order to generate BTA revenues from them. When consumers have high taste for varieties, a large, but not global, agreement is stable.

In the third paper (Al Khourdajie, 2017) we address the case of issue linkage between climate change agreements and customs' union agreements. That is, we analyse a joint climate change and customs' union agreement. While climate agreements suffer from strong free riding incentives due to positive externalities, customs' unions are identified as club good agreements where benefits are exclusive to signatories' only. Accessing these benefits give countries an incentive to join the joint agreement. Furthermore, customs' unions exhibit spillovers toward non-signatories, whereby if these spillovers are negative they create an additional incentive for cooperation. In order to setup the joint agreement, this paper essentially combines the setup of two papers: Finus and Al Khourdajie (2017) and Yi (1996). We analyse coalition formation and stability under three scenarios where governments are either cooperating on one issue only or on both issues at the same time. Our results show that whenever governments cooperate on trade, either individually or with climate change, the grand coalition is always stable. More interestingly, we find that when governments cooperate on climate change only the grand coalition is also stable. However, this holds only when varieties are perfect substitutes.

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Part V

Paper 1: Strategic Environmental  
Policy, International Trade and  
Self-enforcing Agreements: The Role  
of Consumers' Taste for Variety


**Statement of Authorship** (to preface each co-authored paper)

<b>This declaration concerns the article entitled:</b>			
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<b>Publication status (tick one)</b>			
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<b>Candidate's contribution to the paper (detailed, and also given as a percentage).</b>	<p>The candidate contributed to/ considerably contributed to/predominantly executed the...</p> <p>Formulation of ideas:</p> <ul style="list-style-type: none"> <li>- Predominantly contributed to the idea of TFV. (100%)</li> <li>- Considerably contributed to the formulation of all other ideas. (60%)</li> </ul> <p>Design of methodology:</p> <ul style="list-style-type: none"> <li>- Considerably contributed to the design of methodology. (50%)</li> </ul> <p>Experimental work:</p> <p>Presentation of data in journal format:</p> <ul style="list-style-type: none"> <li>- Considerably contributed to the presentation of data in journal format. (50%)</li> </ul>		
<b>Statement from Candidate</b>	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature.		
<b>Signed</b>	Alaa Al Khourdajie	<b>Date</b>	02/03/2017



# Strategic Environmental Policy, International Trade and Self-enforcing Agreements: The Role of Consumers' Taste for Variety

Michael Finus & Alaa Al Khourdajie

August, 2017

## Abstract

We study the coordination of environmental policy within an agreement in the context of international trade. In an  $n$ -country intra-industry trade model, firms produce a horizontally differentiated good and consumers have a taste for variety. Governments choose strategically an emission tax and their membership in an international agreement. We show that only a strong taste for variety reduces the competition among governments sufficiently enough to allow for some form of policy coordination, though full cooperation will never be obtained.

Keywords: strategic environmental policy, international trade, self-enforcing international agreements, horizontal product differentiation, taste for variety

JEL Classification: C72, F18, Q58.

# 1 Introduction

Reaching a meaningful international agreement on climate change has proved difficult over the last three decades. The Kyoto Protocol, signed in 1997, could not even stop the trend of a continuous increase of greenhouse gas emissions world-wide observed since the last century. In the most recent round of climate change negotiations in Paris in December 2015, even though many countries around the world signed an agreement, it is only based on voluntary pledges of governments, without any enforcement mechanism in case of non-compliance. Moreover, even if all governments would deliver on their pledges, global temperature is expected to increase by 2.7-3 degrees Celsius, UNFCCC (2015), much above the widely accepted and recommended target of limiting the temperature increase by 2100 to 2 degrees Celsius compared to per-industrial levels.

Scholars in the game-theoretic literature on the formation of self-enforcing international environmental agreements (IEAs) attribute the difficulty in reaching effective climate change agreement to strong free-riding incentives. These incentives emerge because any non-signatory can enjoy the environmental benefits from reduced emissions without incurring any cost. In the absence of supranational authority that could enforce cooperation on climate change, self-enforcing agreements achieve relatively little. A central finding of this literature is that either participation in an agreement is small or if it is large, then the difference between cooperative and non-cooperative behaviour is small, i.e. cooperation does not really matter. Barrett (1994a) called this the paradox of cooperation. For a recent survey of the literature, including a collection of the most influential papers over the last two decades, see Finus and Caparrós (2015).

Another body of literature explaining the slow progress in addressing transboundary pollution problems, in particular climate change, points at the fear of governments to lose competitiveness in international trade if they pursue a stricter environmental policy than other governments. Based on an extension of the simple strategic trade policy model of Brander and Spencer (1985), strategic environmental policy has been analysed for instance by Barrett (1994b), Conrad (1993) and Kennedy (1994). Under Cournot-competition<sup>1</sup>, Brander and Spencer have shown that governments have an incentive to subsidise production of own firms in order to increase their rent capture. For environmental policy this means that emission taxes are set below marginal damages (Barrett 1994b). This result has been modified in several directions by considering additional components in governments' welfare function. Adding consumers to such a model lowers environmental taxes even further as the consumer surplus increases in the quantity produced and consumed (Kennedy 1994). Similarly, departing from the assumption of a local pollutant and considering transboundary pollution provides further incentives to lower environmental taxes below marginal

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<sup>1</sup>Barrett (1994b) has shown that, probably not surprisingly, many of the results reverse if Bertrand-competition is considered.

damages. Some environmental damages can be externalised and governments understand that domestic production is substituted by foreign production if heavily taxed, which may even increase environmental damages if foreign is more dirty than domestic production (Conrad 1993). However, there is one effect which goes into the opposite direction (Barrett 1994b and Kennedy 1994): if there is oligopolistic competition within a country, governments have incentive to increase emission taxes in order to lower output and to establish a cartel solution. Taken together, strategic trade models offer a rich setting to explain why environmental policies may be distorted, which is also evident from Ulph (1996a and 1996b), considering also the incentive of firms to strategically invest in R&D and by allowing governments to use different environmental policy instruments.

Essentially for a long time, both strands of literature have not been integrated. That is, the IEA literature did not explicitly consider trade and the strategic environmental policy and trade literature did not allow for the formation of agreements, i.e. it did not consider the possibility that governments coordinate their policies. Only recently, Eichner and Pethig produced a series of papers considering both aspects, Eichner and Pethig (2012, 2013, 2014a and 2014b), though their trade model is very different from those mentioned above, and hence their results are difficult to relate to this literature. Overall, these series of papers seem to confirm the paradox of cooperation, with slightly more positive conclusions if the coalition behaves as Stackelberg leader. In contrast, we offer an IEA-model which is very much in the spirit of the strategic environmental policy and trade literature. Our model considers governments which care for the profits of their firms, the utility of their consumers and environmental damages, which are the result of a global pollutant. They choose strategically an emission tax and their membership in an international agreement. We allow for horizontal product differentiation where consumers' taste for variety is captured. Thus, our paper benefits from contributions by Yi (1996) and (2000) and Loke and Winters (2012) who look at international trade, trade agreements and taste for variety, but who ignore environmental damages and their effect on governments' strategic behaviour.

Our results confirm the pessimistic conclusion which mainly emerges from the IEA literature. Agreements are small at best and may not exist at all due to strong free-rider incentives. If consumers have a low taste for variety, i.e. domestic and foreign varieties are viewed as good substitutes by consumers, agreement formation fails. Only with a sufficiently high taste for variety, strategic interaction of governments is sufficiently mitigated such that small agreements are stable. In what follows, section 2 presents our model and some important properties, helpful in analysing coalition formation. Section 3 develops our results, including an in-depth analysis of the driving forces of coalition formation and the strategic interaction between signatories and non-signatories to an agreement. In section 4, we summarise our main results and conclude.

## 2 Model

### 2.1 Payoff Function

Consider an intra-industry trade model with  $n$  *ex ante* symmetric countries with a representative firm and consumer in each country. We denote the set of countries by  $N$ . Firms produce a horizontally differentiated good, i.e. the same good but in different varieties where each firm produces one variety. Firms compete in a Cournot-fashion. Markets are segmented and each firm supplies its good to the domestic and all foreign markets. Because of the segmentation of markets, firms play a separate Cournot game in each market.<sup>2</sup> Transport costs are assumed away as usual.

The welfare of country  $i$  is given by:

$$W_i = CS_i + PS_i + TR_i - D_i \quad (1)$$

where  $CS_i$  represents country  $i$ 's consumer surplus,  $PS_i$  country  $i$ 's producer surplus,  $TR_i$  is the tax revenue from the emission tax imposed by the government  $i$  on its domestic firm, and  $D_i$  is the pollution damage faced by country  $i$ .

Consumers are identical and their preferences are represented by a quasi-linear utility function over two goods (see equation (2) below). The first good is the horizontally differentiated and traded good. The second good is a numeraire good, representing the composition of all other goods. Utility is linear in the numeraire good and quadratic in the differentiated good.

We assume that consumers have a taste for variety (Dixit and Stiglitz, 1977). That is, their utility depends not only on the total quantity consumed but also on the composition of the quantities of the differentiated good (Yi, 1996 and 2000). The taste for variety (abbreviated TFV hereafter) is captured by parameter  $\gamma \in [0, 1]$ . High values of  $\gamma$  imply a low taste for variety and for  $\gamma = 1$  varieties are perfect substitutes. In contrast, low values of  $\gamma$  represent a high preference for a diverse and balanced consumption bundle and for  $\gamma = 0$  varieties cannot be substituted at all.<sup>3</sup>

More specifically, let the representative consumer's utility in country  $i$  be given by  $u_i$ :

$$u_i(q_i; M_i) = v_i(q_i) + M_i = aQ_i - \frac{\gamma}{2}Q_i^2 - \frac{1-\gamma}{2} \sum_{k \in N} q_{ik}^2 + M_i \quad (2)$$

where  $v_i$  represents the utility from consuming the horizontally differentiated and traded good and  $M_i$  represents the utility from consuming the numeraire good;  $q_i =$

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<sup>2</sup>See Appleyard and Field (2014) as well as Helpman and Krugman (1985) for further background.

<sup>3</sup>An extension could be the "ideal variety" approach where consumers have not only a general preference for the variety of a good but also a preference for a particular variety. One application is a bias towards the domestically produced variety (Di Comite *et al*, 2014).

$(q_{i1}, \dots, q_{in})$  is a vector of varieties consumed by consumers in country  $i$ , with  $q_{ik}$  representing country  $i$ 's consumption of country  $k$ 's variety<sup>4</sup>;  $a$  is a positive demand parameter and  $Q_i = \sum_{k \in N} q_{ik}$  is country  $i$ 's total consumption of all varieties, supplied by all countries  $k$ .

In this paper, in most parts, we will focus our analysis on two extreme TFV scenarios for analytic tractability: the “no TFV” scenario with  $\gamma = 1$  and the “maximum TFV” scenario with  $\gamma = 0$ .

From (2), country  $i$ 's inverse demand function for country  $k$ 's variety follows from:

$$p_{ik} = \frac{\partial u_i}{\partial q_{ik}} \iff p_{ik} = a - (1 - \gamma)q_{ik} - \gamma Q_i \iff p_{ik} = a - q_{ik} - \gamma \sum_{l \in N, l \neq k} q_{il} \quad (3)$$

where  $p_{ik}$  represents the price faced by consumers in country  $i$  consuming the variety of country  $k$  and  $\sum_{l \in N, l \neq k} q_{il}$  is the sum of all consumed varieties produced by all firms except firm  $k$  in country  $i$ .

From (2) and (3), the consumer surplus in country  $i$  is given by :

$$CS_i = aQ_i - \frac{\gamma}{2}Q_i^2 - \frac{1 - \gamma}{2} \sum_{k \in N} q_{ik}^2 - \sum_{k \in N} q_{ik}p_{ik} \quad (4)$$

where the last term in (4) represents consumers' spending.

The producer surplus of representative firm  $i$  (in country  $i$ ) is the sum of its profit in each market:

$$PS_i = \sum_{k \in N} \pi_{ki} = \sum_{k \in N} q_{ki}(p_{ki} - c - t_i) \quad (5)$$

where  $\pi_{ki}$  is firm  $i$ 's profit in market  $k$  from selling quantity  $q_{ki}$  at price  $p_{ki}$  where  $c$  is the constant marginal cost and  $t_i$  is the emission tax imposed by country  $i$ 's government on its firm's output, which assumes that emissions are linked to quantities by a constant emission-output coefficient. Without loss of generality, we set this coefficient to 1. Assuming constant marginal costs implies that different markets are independent. That is, given our segmented market structure, under the assumption of constant marginal cost changes in demand for a differentiated good in one market have no effect on marginal costs of production elsewhere, (Loke and Winters, 2012).

The tax revenue,  $TR_i$ , is given by:

$$TR_i = t_i \sum_{k \in N} q_{ki} \quad (6)$$

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<sup>4</sup>Throughout the paper the first subscript indicates the market in which the variety is consumed and the second subscript indicates the market in which it is produced.

and damages from global pollution faced by country  $i$  are given by:

$$D_i = \delta \sum_{i \in N} Q_i. \quad (7)$$

where  $\delta$  is a damage parameter,  $\sum_{i \in N} Q_i$  is total consumption in every country  $i$  and hence total emissions (due to our assumption of a constant emission output coefficient of 1). That is, emissions constitute a pure public bad: damages depend on total emissions.

## 2.2 Coalition Formation Game

We assume a three-stage coalition formation game, which unfolds as follows.

*Stage 1, Choice of Membership:* all countries decide simultaneously whether to join coalition  $S$  with  $m$  the cardinality of  $S$ . Countries which do not join  $S$  act as singletons. A typical signatory will be denoted by  $i$  and a non-signatory by  $j$ .

Following d'Aspremont et al (1983), a coalition is called stable if it is internally and externally stable. Internal stability means that no signatory has an incentive to leave coalition  $S$ , whereas external stability means that no non-signatory has an incentive to join coalition  $S$ . We assume for simplicity that in the case of indifference a non-signatory joins coalition  $S$ .

Internal stability:

$$W_i(S) - W_i(S \setminus \{i\}) \geq 0 \quad \forall i \in S \quad (8)$$

External stability:

$$W_j(S) - W_j(S \cup \{j\}) > 0 \quad \forall j \in N \setminus S. \quad (9)$$

*Stage 2, Choice of Policy Level:* all countries choose simultaneously their emission tax.

- Signatories choose their joint emission tax  $t_i$  (implemented uniformly in all signatory countries) in order to maximise the joint welfare of coalition  $S$ :  $\max_{t_i} \sum_{i \in S} W_i$
- Non-signatories choose their individual tax  $t_j$  in order to maximise their individual welfare:  $\max_{t_j} W_j$ .

*Stage 3, Choice of Output:* all firms choose simultaneously and non-cooperatively their segmented market outputs by maximising profits:  $\max_{q_{1i}, \dots, q_{ni}} PS_i$ .

The game is solved by backwards induction.

## 2.3 Properties of the Game

We define the following properties to analyse the incentive structure to form coalitions and the associated welfare implications.

For all  $S \subset N$ ,  $S \neq \emptyset$ , and for all  $S' = S \cup \{j\}$  where  $S' \subseteq N$ :

- **Superadditivity:** a coalition game is (strictly) superadditive if:

$$\sum_{i \in S'} W_i(S') \geq (>) \sum_{i \in S} W_i(S) + W_j(S).$$

- **Positive Externality:** a coalition game exhibits a (strict) positive externality if:

$$W_j(S') \geq (>) W_j(S) \quad \forall j \notin S \text{ and } j \notin S'.$$

- **Full Cohesiveness:** a coalition game is (strictly) fully cohesive if:

$$\sum_{i \in S'} W_i(S') + \sum_{j \in N \setminus S'} W_j(S') \geq (>) \sum_{i \in S} W_i(S) + \sum_{j \in N \setminus S} W_j(S).$$

Superadditivity provides an incentive to join a coalition whereas the positive externality captures the incentive to free-ride. In terms of forming large stable coalitions, the two properties work in opposite directions and typically for large coalitions the positive externality effect is weaker than the superadditivity effect. Full cohesiveness justifies the search for large stable coalitions, even if the grand coalition is not stable. Essentially, global welfare increases when the coalition is enlarged gradually and obtains its maximum in the grand coalition.

## 3 Results

### 3.1 Third Stage

In this section, we derive results for the third stage. The profit of firm  $i$  in market  $k$  is given by  $\pi_{ki} = q_{ki}(p_{ki} - c - t_i)$ . Substituting the inverse demand function from equation (3) above, we derive the following first order condition:

$$\frac{\partial \pi_{ki}}{\partial q_{ki}} = a - c - t_i - (2 - \gamma)q_{ki} - \gamma Q_k = 0 \iff a - c - t_i - 2q_{ki} - \gamma \sum_{l \in N, l \neq i} q_{kl} = 0 \quad (10)$$

where  $Q_k$  is the total quantity consumed in market  $k$  and  $\sum_{l \in N, l \neq i} q_{kl}$  is the sum of all consumed varieties by consumers in market  $k$  from all firms except from firm  $i$ . It is easy to see that reaction functions ( $q_{ki} = r_i(\sum_{l \in N, l \neq i} q_{kl})$ ) have a slope of  $-\gamma/2$ . Hence, the equilibrium is unique; the absolute value of the slope of the reaction function increases with the taste of variety parameter  $\gamma$  and as  $\gamma$  approaches zero, the strategic interaction among firms vanishes. Moreover, it is easy to see that a necessary condition for positive quantities is  $a > c$ . Below, we will further develop this non-negativity condition in order to ensure interior solutions.

Solving the  $n$  first order conditions in market  $k$  simultaneously, gives:

$$q_{ki} = \frac{(a - c)(2 - \gamma) - t_i(\gamma(n - 2) + 2) + \gamma \sum_{k \in N, k \neq i} t_k}{((n - 1)\gamma + 2)(2 - \gamma)}. \quad (11)$$

Given our assumption of segmented market structure each firm supplies its good to the domestic and all foreign markets. Furthermore, because of the segmentation of markets, firms play a separate and identical Cournot game in each market. Therefore, since the tax imposed on production is not differentiated based on the target market, the equilibrium quantity of firm  $i$ 's variety is the same in all markets  $k$ .

Equation (11) represents the output of any firm in the case of no cooperation, i.e. singletons market structure. It is evident that quantities decrease in own taxes and increase in foreign taxes. In the case of cooperation, if we already account for the fact of a symmetric tax in stage 2 with all signatories choosing the same tax rate  $t_i$  and all non-signatories choose the same tax rate  $t_j$  (and typically  $t_i \neq t_j$ ), we can derive the equilibrium quantity for a signatory's and a non-signatory's firm as follows. In the case of a signatory's firm, the last term in the numerator in (11) ( $\gamma \sum_{k \in N, k \neq i} t_k$ ) is split into other signatories' taxes ( $t_i\gamma(m - 1)$ ) and all non-signatories' taxes ( $t_j\gamma(n - m)$ ), and hence we have for a signatory's firm

$$q_{i \in S}^* = \frac{(a - c)(2 - \gamma) - t_i(\gamma(n - m - 1) + 2) + t_j(\gamma(n - m))}{((n - 1)\gamma + 2)(2 - \gamma)} \quad (12)$$

In the case of a non-signatory's firm, the last term in the numerator is split into all signatories' taxes ( $t_i\gamma m$ ) and other non-signatories' taxes ( $t_j\gamma(n - m - 1)$ ),<sup>5</sup> and hence we have for a non-signatory's firm

$$q_{j \notin S}^* = \frac{(a - c)(2 - \gamma) + \gamma m t_i - t_j(\gamma(m - 1) + 2)}{((n - 1)\gamma + 2)(2 - \gamma)} \quad (13)$$

with the total equilibrium consumption in market  $k$ ,  $Q_k^* = m q_{i \in S}^* + (n - m) q_{j \notin S}^*$ , given by:

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<sup>5</sup>Given that we are dealing with a non-signatory, we change the notation of the second term in the numerator of (11) to:  $t_j(\gamma(n - 2) + 2)$ .



$$Q_k^* = \frac{n(a - c) - t_j(n - m) - mt_i}{(n - 1)\gamma + 2} \quad (14)$$

This leads to the following conclusions.

**Proposition 1 - The Effects of Taxes on Equilibrium Quantities**

*Consider the third stage and a market  $k$ . Suppose a coalition  $S$  has formed in the first stage and all players have chosen their equilibrium taxes in stage 2.*

*The quantity of firm  $i$ 's ( $j$ 's) variety in a signatory country (non-signatory country) decreases with the level of signatories' (non-signatories') equilibrium taxes,  $\frac{\partial q_{ki}^*}{\partial t_i} < 0$  ( $\frac{\partial q_{kj}^*}{\partial t_j} < 0$ ), and increases with the level of non-signatories' (signatories') equilibrium taxes,  $\frac{\partial q_{ki}^*}{\partial t_j} > 0$  ( $\frac{\partial q_{kj}^*}{\partial t_i} > 0$ ), except for  $\gamma = 0$  in which case  $\frac{\partial q_{ki}^*}{\partial t_j} = 0$  ( $\frac{\partial q_{kj}^*}{\partial t_i} = 0$ ). The total quantity in market  $k$  decreases in signatories' and non-signatories equilibrium tax,  $\frac{\partial Q_k^*}{\partial t_i} < 0$  and  $\frac{\partial Q_k^*}{\partial t_j} < 0$  irrespective of  $\gamma$ .*

**Proof:** Follows directly from equations (12) to (14) above. **Q.E.D.**

Thus, quantities produced by a firm for a particular market are negatively affected by own taxes and positively affected by foreign taxes. Given that a firm produces the same quantities for all markets, also the same holds for total production of a firm. Only for the maximum TFV, i.e.  $\gamma = 0$ , will a firm's output not be affected by the tax of a foreign government imposed on a foreign firm. Then, essentially, firms act in each segmented market like a monopolist as consumers do not substitute different varieties at all. In other words, firms do not compete and hence are only affected by their own government's taxes.

The same relationship will hold when considering second stage equilibrium taxes, with essentially two groups of players. Signatories' taxes influence non-signatories' quantities negatively and vice versa, except for  $\gamma = 0$ . Hence, for instance, if governments in signatory countries want to boost their firms' profit by subsidising their firms, this will automatically reduce foreign firms' quantities. However, if they decide to tax their firms to reduce total output in order to stabilise the market price, then this objective is only partially achieved because foreign firm's output will increase. A similar conflict occurs if signatories tax their firms to reduce environmental damages because foreign quantities and hence emissions will increase. Only for  $\gamma = 0$  this strategic interaction breaks down.

### 3.2 Second Stage

In this section, we derive equilibrium taxes in the second stage. In order to disentangle the incentives present in the payoff function in equation (1) above, we consider 3 additional scenarios of this payoff function representing partial welfare preferences. This will help understanding the importance of each welfare component in the payoff function and their effects on equilibrium taxes as well as the driving forces for cooperation. Nevertheless, this is a theoretic exercise only and our main focus in the paper is on the full model, describe in the last scenario below.

1.  $W_i^1 = PS_i + TR_i$
2.  $W_i^2 = CS_i + PS_i + TR_i$
3.  $W_i^3 = PS_i + TR_i - D_i$
4.  $W_i^4 = CS_i + PS_i + TR_i - D_i$

The first scenario replicates the simple Brander and Spencer (1985) model of trade, henceforth abbreviated as B&S-model. Consumers are ignored due to the assumption that all quantities are sold to a third market. The second and the third scenarios add one welfare component, consumer surplus and damages, respectively. The fourth scenario represents our full model. For analytic tractability, we henceforth consider two parameter values of  $\gamma$ , namely the “no TFV” scenario with  $\gamma = 1$ , and the “maximum TFV” scenario with  $\gamma = 0$ . Equilibrium taxes for each welfare scenario are given in Appendix 1. We denote signatories’ equilibrium taxes under welfare scenario 1 by  $t_i^*(PS, TR)$ , scenario 2 by  $t_i^*(CS, PS, TR)$  and so on, and the same applies for non-signatories’ equilibrium taxes.

Inserting equilibrium taxes into equilibrium quantities reveals that we need to impose non-negativity constraints on parameter values in order to ensure positive outputs. Essentially, these constraints boil down to requesting that the demand parameter  $a$  is larger than marginal production cost  $c$  plus a multiple of marginal damages. The exact constraints are stated in Appendix 2, which henceforth are assumed to hold.

We now consider how signatories’ and non-signatories’ taxes change across the different welfare scenarios, taking welfare scenario 1, the B&S scenario, as a benchmark.

## Proposition 2 - Comparing Equilibrium Taxes Across Different Welfare Scenarios

Assume some coalition with  $m$  signatories has formed in the first stage and let  $n > m > 2$ .

*Signatories' taxes:*

- $t_i^*(PS, TR, D) > t_i^*(PS, TR) > t_i^*(CS, PS, TR)$  for  $\gamma = \{0, 1\}$ .
- $t_i^*(PS, TR, D) > t_i^*(CS, PS, TR, D) > t_i^*(CS, PS, TR)$  for  $\gamma = \{0, 1\}$ .

*Non-signatories' taxes:*

For  $\gamma = 1$ :

- $t_j^*(PS, TR, D) < t_j^*(PS, TR) < t_j^*(CS, PS, TR)$ .
- $t_j^*(PS, TR, D) < t_j^*(CS, PS, TR, D) < t_j^*(CS, PS, TR)$ .

For  $\gamma = 0$ :

- $t_j^*(PS, TR, D) > t_j^*(PS, TR) > t_j^*(CS, PS, TR)$ .
- $t_j^*(PS, TR, D) > t_j^*(CS, PS, TR, D) > t_j^*(CS, PS, TR)$ .

**Proof:** See Appendix 3. **Q.E.D.**

We first note that signatories' equilibrium taxes are lowered compared to the Brender and Spencer scenario when consumers enter governments' welfare function and are increased when instead damages are considered by governments. The reason is that the consumer surplus is negatively affected by taxes whereas damages are reduced through taxes. Hence, in terms of equilibrium taxes, consumers call for lower and damages for higher equilibrium taxes. Since both effects go in opposite directions, equilibrium taxes in the full model may be higher or lower than those in the B&S-scenario. De facto this depends on the relative weight of the consumer and damage component in the welfare function. In our model, the larger the damage parameter  $\delta$  compared to the demand parameter  $a$  the higher will be the tax and vice versa.

For non-signatories, we observe the same ranking as for signatories if  $\gamma = 0$  because then the strategic interaction among firms vanishes. As shown in Proposition 1, if  $\gamma = 0$ , quantities only depend on own taxes. In contrast for  $\gamma = 1$ , the strategic interaction among firms is at its maximum and hence also among governments. The ranking of equilibrium taxes for the different welfare scenarios of non-signatories is reversed to those of signatories. For instance, adding the damages to the B&S welfare scenario leads to lower equilibrium taxes for non-signatories, already indicating the

strategic interaction among signatories and non-signatories, where non-signatories free-ride on signatories' emission reduction efforts. This is one version of the free-rider behavior of non-signatories undermining the formation of large stable coalitions which will be analysed in more detail below.

We now turn to comparing signatories' and non-signatories' taxes within each welfare scenarios, which gives further insights into the strategic interaction among signatories and non-signatories.

### Proposition 3 - Comparing Equilibrium Taxes within each Welfare Scenario

*Scenario  $W_i^1 = PS_i + TR_i$ :*

- For  $\gamma = 1$ :  $t_i^*(PS, TR) > t_j^*(PS, TR)$ ;  $\frac{\partial t_i^*(PS, TR)}{\partial m} > 0$  and  $\frac{\partial t_j^*(PS, TR)}{\partial m} < 0$ .
- For  $\gamma = 0$ :  $t_i^*(PS, TR) = t_j^*(PS, TR)$ ;  $\frac{\partial t_i^*(PS, TR)}{\partial m} = 0$  and  $\frac{\partial t_j^*(PS, TR)}{\partial m} = 0$ . in which case

*Scenario  $W_i^2 = CS_i + PS_i + TR_i$ :*

- For  $\gamma = 1$ :  $t_i^*(CS, PS, TR) = t_j^*(CS, PS, TR)$ ;  $\frac{\partial t_i^*(CS, PS, TR)}{\partial m} = 0$  and  $\frac{\partial t_j^*(CS, PS, TR)}{\partial m} = 0$ .
- For  $\gamma = 0$ :  $t_i^*(CS, PS, TR) < t_j^*(CS, PS, TR)$ ;  $\frac{\partial t_i^*(CS, PS, TR)}{\partial m} < 0$  and  $\frac{\partial t_j^*(CS, PS, TR)}{\partial m} = 0$ .

*Scenario  $W_i^3 = PS_i + TR_i - D_i$ :*

- For  $\gamma = 1$ :  $t_i^*(PS, TR, D) > t_j^*(PS, TR, D)$ ;  $\frac{\partial t_i^*(PS, TR, D)}{\partial m} > 0$  and  $\frac{\partial t_j^*(PS, TR, D)}{\partial m} < 0$ .
- For  $\gamma = 0$ :  $t_i^*(PS, TR, D) > t_j^*(PS, TR, D)$ ;  $\frac{\partial t_i^*(PS, TR, D)}{\partial m} > 0$ , and  $\frac{\partial t_j^*(PS, TR, D)}{\partial m} = 0$ .

*Scenario  $W_i^4 = CS_i + PS_i + TR_i - D_i$ : in which case*

- For  $\gamma = 1$ :  $t_i^*(CS, PS, TR, D) > t_j^*(CS, PS, TR, D)$ ;  $\frac{\partial t_i^*(CS, PS, TR, D)}{\partial m} > 0$  and  $\frac{\partial t_j^*(CS, PS, TR, D)}{\partial m} < 0$ .
- For  $\gamma = 0$ :  $t_i^*(CS, PS, TR, D) > t_j^*(CS, PS, TR, D)$  and  $\frac{\partial t_i^*(CS, PS, TR, D)}{\partial m} > 0$  if  $\delta m + c \leq a < 2n\delta + c$ ;  $t_i^*(CS, PS, TR, D) \leq t_j^*(CS, PS, TR, D)$  and  $\frac{\partial t_i^*(CS, PS, TR, D)}{\partial m} \leq 0$  if  $a \geq 2\delta n + c$ ;  $\frac{\partial t_j^*(CS, PS, TR, D)}{\partial m} = 0$ .

Taken together:

Welfare Scenarios	Direction of Change		Strategic Interaction	
	$\gamma = 1$	$\gamma = 0$	$\gamma = 1$	$\gamma = 0$
$PS_i + TR_i$	$\uparrow, \downarrow$	$\mathbf{0}, 0$	<i>substitutes</i>	<i>independent</i>
$CS_i + PS_i + TR_i$	$\mathbf{0}, 0$	$\downarrow, 0$	<i>independent</i>	<i>independent</i>
$PS_i + TR_i - D_i$	$\uparrow, \downarrow$	$\uparrow, 0$	<i>substitutes</i>	<i>independent</i>
$CS_i + PS_i + TR_i - D_i$	$\uparrow, \downarrow$	$\uparrow \downarrow, 0$	<i>substitutes</i>	<i>independent</i>

**Proof:** See Appendix 4. **Q.E.D.**

There are at least two interesting aspects in Proposition 3. The first aspect relates to the comparison between signatories' and non-signatories' equilibrium taxes where the former internalise externalities within their group. The second aspect relates to the strategic interaction between signatories' and non-signatories' taxes when the coalition is enlarged.

For the B&S-scenario and for the standard assumption of  $\gamma = 1$ , signatories impose a higher tax than non-signatories. As firms compete in a Nash-Cournot fashion, signatories' governments de facto try to enforce a cartel solution via taxes. These high taxes result in higher prices and lead to a reduction in signatories firms' output. Though taxes reduce firms profits, the government collects these taxes and hence taxes are welfare neutral in this model. If the grand coalition forms, output is identical to the output of a monopolist. For  $\gamma = 0$ , there is no competition among firms which act like monopolists for their own variety. Hence, there is no externality across firms and hence also not among governments. In other words, there are no externalities in the B&S-model for  $\gamma = 0$ .

For the second scenario, adding consumers to the B&S-scenario, signatories' and non-signatories' taxes are the same for  $\gamma = 1$ . As mentioned earlier, in the B&S-scenario signatories impose higher taxes than non-signatories. In this scenario, adding consumers calls for lower equilibrium taxes in order to subsidise consumption. Therefore, compared to the B&S-model, we have in this scenario two opposing driving forces: one calling for a higher tax and the other is calling for a lower tax. We find in this case signatories and non-signatories have the same equilibrium tax for  $\gamma = 1$ , which means that the two opposing driving forces are canceling themselves leading to no externalities across countries. In which case, cooperation in this scenario is meaningless since all countries, signatories and non-signatories, are imposing the same tax. This is different for  $\gamma = 0$ . In the B&S-model, there was no externality for

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<sup>6</sup>The first column, Direction of Change, illustrates how signatories' and non-signatories' taxes change with the coalition size. The first entry (arrow) relates to signatories' taxes and the second to non-signatories' ones. An entry of  $\mathbf{0}$  for signatories means that there is no need for coordination among players. The second column illustrates the strategic interaction between signatories' and non-signatories' taxes. Intuition would suggest that in terms of forming stable coalitions, for a given welfare scenario, this will be easier if taxes are independent than if they are strategic substitutes.

$\gamma = 0$  but when adding the consumer, there is a positive externality from subsidising consumption. Therefore, signatories impose lower tax than non-signatories.

For the third scenario, adding damages to the B&S-scenario, signatories choose a higher tax than non-signatories in order to internalise the negative externality stemming from emissions. Like the price externality, the emission externality stems from output and hence taxes of signatories are increased even further compared to the B&S-scenario. In the fourth scenario, the full model, effects from scenario 2 and 3 play together. For  $\gamma = 1$ , this means that signatories have a higher tax than non-signatories. For  $\gamma = 0$ , it implies that signatories' taxes can be higher or lower than non-signatories, depending on the relative importance of the consumer surplus compared to damages for signatories' internalisation strategy, which, in our model, relates to the ratio between the demand parameter  $a$ , production cost parameter  $c$  and damage cost parameter  $\delta$ .

The second aspect of Proposition 3 is the strategic interaction between signatories' and non-signatories' taxes. In the case of "no TFV" with  $\gamma = 1$ , signatories' and non-signatories' taxes are strategic substitutes in most welfare scenarios where signatories' taxes are increasing with the coalition size  $m$  whereas non-signatories' taxes are decreasing. The exception is the second scenario because externalities cancel out. In the case of "maximum TFV" with  $\gamma = 0$ , signatories' and non-signatories' taxes are strategically independent. Signatories' taxes are either increasing or decreasing with the coalition size depending on the externality they are internalising, except in the first welfare scenario in which they remain constant as there is no externality. In scenario 2 (3) signatories' taxes decrease (increase) with the coalition size because because of the positive externality on consumers (damages). Scenario 4 combines the effects of scenarios 2 and 3 and hence signatories' taxes decrease with coalition size if the demand parameter  $a$  is sufficiently large compared to marginal production costs and global marginal damages. For all welfare scenarios with  $\gamma = 0$ , non-signatories' taxes do not change with the coalition size  $m$  due to the independence of varieties.

### 3.3 Properties of the Coalition Game

In this section, we analyse the properties of each welfare scenario for the two scenario: "no TFV" with  $\gamma = 1$  and "maximum TFV" with  $\gamma = 0$ . These properties have been defined in subsection 2.3 above.

## Proposition 4 - Properties of the Coalition Game

*In the coalition game, the properties positive externality and full cohesiveness hold strictly for each of the four welfare scenarios whenever there is an externality across players. In the scenarios where there is no externality across players, these properties hold weakly.*

*For all welfare scenarios, superadditivity holds for  $\gamma = 0$  and fails for  $\gamma = 1$ . For  $\gamma = 1$  it only holds for the move from a coalition with  $n - 1$  signatories to the grand coalition with  $n$  signatories.*

*More specifically: (Legend: “+”= holds strictly, “0”= holds weakly, and “-” generally fails.)*

Welfare Scenarios	Positive Externality		Superadditivity		Full Cohesiveness	
	$\gamma = 1$	$\gamma = 0$	$\gamma = 1$	$\gamma = 0$	$\gamma = 1$	$\gamma = 0$
$PS_i + TR_i$	+	0	-	0	+	0
$CS_i + PS_i + TR_i$	0	+	0	+	0	+
$PS_i + TR_i - D_i$	+	+	-	+	+	+
$CS_i + PS_i + TR_i - D_i$	+	+	-	+	+	+

**Proof:** See Appendix 5. **Q.E.D.**

Proposition 4 confirms that the normative property of the game full cohesiveness holds. The larger are coalitions, the larger will be global welfare, which obtains its maximum in the grand coalition. It also confirms that non-signatories benefit from the enlargement of the coalition via positive externalities. This provides an incentive to free-ride. Interestingly, the incentive to join a coalition, captured by the property superadditivity, is only positive if  $\gamma = 0$  but is negative if  $\gamma = 1$  and whenever coalition formation would matter (i.e. full cohesiveness holds strictly). In the latter case, signatories’ taxes increase with the coalition size and the reverse is true for non-signatories as shown in Proposition 3. That is, strategies are substitutes, and hence the efforts of signatories are undermined by non-signatories’ reaction. This countervailing or leakage effect renders the enlargement of the coalition not successful. As recently shown in Bayramoglu, Finus and Jacques (2016), if the move from a coalition with  $m - 1$  to  $m$  is not superadditive, then coalition with  $m$  signatories cannot be internally stable. In other words, superadditivity is a necessary (though not sufficient) condition for internal stability in a positive externality game. Hence, if superadditivity fails for all  $m \leq n - 1$  for  $\gamma = 1$ , we only need to test for stability of the grand coalition. Our overall results are summarised in Proposition 5 below, which looks at the stability of coalitions in the first stage.

### 3.4 First Stage

In this section, we present the results for the first stage, i.e. the stability of coalitions.

#### Proposition 5 - Coalition Stability

Let  $m^*$  denote the size of an internally and externally stable coalition. For the four welfare scenarios, whenever there is an incentive for countries to coordinate their policy (i.e.  $\frac{\partial t_i^*}{\partial m} \neq 0$ ), the following results are obtained:

For  $\gamma = 1$ :  $m^* = 1$  and for  $\gamma = 0$ :  $m^* = 3$ .

More specifically:

Welfare Scenarios	$I\mathcal{E}ES$	
	$\gamma = 1$	$\gamma = 0$
$PS_i + TR_i$	$m^* = 1$	-
$CS_i + PS_i + TR_i$	-	$m^* = 3$
$PS_i + TR_i - D_i$	$m^* = 1$	$m^* = 3$
$CS_i + PS_i + TR_i - D_i$	$m^* = 1$	$m^* = 3$

**Proof:** See Appendix 6. **Q.E.D.**

Proposition 5 shows that if  $\gamma = 1$  there are no stable coalitions in the main scenario as well as scenarios 1 and 3. As we showed in Proposition 4 above, positive externalities persist in these scenarios. Therefore, the positive spillovers of signatories' efforts provide the incentives for free riding. This is a common finding in the IEAs literature, check Barrett (1994a) and Finus and Caparrós (2015). Furthermore, the incentives to join a coalition, captured by the property superadditivity, are non-existent under  $\gamma = 1$ . This is because when varieties are perfect substitutes the efforts of signatories are undermined by non-signatories' reactions. That is, whenever signatories increase their taxes to internalise the damage externalities for instance, non-signatories react by decrease their taxes leading to emission leakage which renders the enlargement of the coalition not successful. This can be related to two previous results. In Proposition 3 we showed that taxes are strategic substitutes under  $\gamma = 1$  because firms are interdependent due to perfect substitution, and in Proposition 4 we showed that this implied that superadditivity failed.

As for scenario 2 under  $\gamma = 1$ , coalition formation is meaningless due to the fact that signatories' and non-signatories' taxes are the same as we showed in Proposition 3 above. The reason that all countries, signatories and non-signatories, impose the same tax is that we have in this scenario two opposing driving forces: one calling for a higher tax (to enforce the cartel solution) and the other is calling for a lower tax (to subsidise consumption). We find in this case signatories and non-signatories have the same equilibrium tax, which means that the two opposing driving forces



are canceling themselves leading to no externalities across countries. In which case, cooperation in this scenario is meaningless as all countries are imposing the same tax.

Under  $\gamma = 0$  we show that there is stable coalition of three countries in the main scenario as well as scenarios 2 and 3. This can also be inferred from our previous results. When varieties are independent positive externalities also persist due to the spillovers of signatories' efforts, providing the incentives for free riding. However, the incentives to join a coalition are stronger under  $\gamma = 0$ . The reason for that is because of varieties' independence, there is no externality across firms (as we showed in Proposition 1) and hence also not among signatory and non-signatory governments. This is evident from Proposition 3 where non-signatories' taxes do not change with the coalition size  $m$  due to the independence of varieties. In other words, under  $\gamma = 0$  the efforts of signatories are not undermined by non-signatories. For these reasons, we find superadditivity holds and hence the incentives to join a coalition are stronger under  $\gamma = 0$ . Nevertheless, these incentives are not strong enough to outweigh the positive externalities and hence they only lead to small stable coalitions. In summary, only when varieties are differentiated, strategic interaction among governments is sufficiently mitigated such that small agreements are stable. These findings are inline with the pessimistic conclusion which mainly emerges from the IEA literature under oligopoly (Barrett 1994b and Kennedy 1994).

As for scenario 1, coalition formation is meaningless due to the fact that under  $\gamma = 0$  there is no competition among firms which act like monopolists for their own variety. Hence, there is no externality across firms and also not among governments. In other words, there are no externalities in the B&S-model for  $\gamma = 0$  and therefore coalition formation is meaningless.

It is interesting that these results for both values of  $\gamma$  hold irrespective of the weight consumers and damages perceived in governments' welfare function (i.e. irrespective of the welfare scenario), which stresses that they are quite robust.

It is probably not surprising that for intermediate values of  $\gamma$  between 0 and 1, one finds that the equilibrium coalition size lies between  $m^* = 1$  and  $m^* = 3$ . More specifically, we find for  $\gamma = 0.6$  the equilibrium coalition size is  $m^* = 2$ , which reflect the monotonicity of our results with respect to  $\gamma$ .

## 4 Concluding Remarks

In this paper, we analysed a strategic trade model in the spirit of Brander and Spencer (1985). We introduced three additional features, which have been considered in the literature, though in isolation. Firstly, consumers matter for governments because goods are not sold to a third market. Moreover, environmental damages matter because production releases a global pollutant. Second, we consider horizontal product differentiation with consumers having a taste for variety (TFV). For analytical

tractability, we focused on two extreme assumptions of TFV: no TFV and maximum TFV where the former assumption corresponds to the standard assumption in the literature that goods are perfect substitutes. Thirdly, we considered the possibility that governments can coordinate their policy by forming coalitions. Policy coordination is related to an emission tax, which is de facto an output tax because of a constant output-emission ratio. Stability of a coalition leading to an agreement was tested by invoking the concept of internally and externally stable cartels.

We demonstrated that the formation of agreements is globally beneficial. Global welfare increases with the size of agreements and obtains its maximum if the grand coalition forms (full cohesiveness). However, the grand coalition or even smaller coalitions may not be stable because of two reasons. Firstly, the benefits from policy coordination are non-exclusive, a features which we related to the property of positive externality of coalition formation. Secondly, the gains from cooperation for those involved in enlarging coalitions may be small or even negative if policy instruments are strategic substitutes. That is, superadditivity fails.

We showed that for the “no TFV” scenario, signatories of an agreement increase their taxes with the size of the agreement. Signatory governments have an incentive to internalise two negative externalities, both associated with high quantities. A reduction of output stabilises the price in the output cartel and also reduces environmental damages. Non-signatories free-ride on signatories’ efforts and lower their taxes. Hence, taxes are strategic substitutes between signatories and non-signatories. In our model, this meant that no agreement was stable. In contrast, for the “maximum TFV” scenario, foreign taxes have no effect on domestic firms’ output. In the context of an agreement, this implies that taxes of signatories (non-signatories) have no effect on the output of non-signatories’ (signatories’) firms. We found that this implies that taxes between signatories and non-signatories become strategically independent. Regardless whether signatories increase or decrease their tax with the size of the agreement, non-signatories’ equilibrium taxes do not change. This reduces the free-rider incentive, but it remains positive, which explains that this led only to small stable coalitions.

To our knowledge, this is the first attempt to introduce consumers’ taste for variety to the literature of international environmental agreements and trade. Our stylized model allows for exploring future research avenues in terms of additional policy instruments, like tax border adjustments, relaxing the symmetry assumption and further investigations of sub-features of TFV, such as ideal varieties or asymmetric consumers’ TFV between countries.

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## 6 Appendixes

A detailed appendix with the full details of all derivations is available upon request. Below, we summarise the most important steps in the derivation in a compact form for  $\gamma = 1$  and  $\gamma = 0$ .

### 6.1 Equilibrium Taxes for all Scenarios

For each scenario, we derive the F.O.C.s for signatories and non-signatories in stage 2 of the game. Solving these conditions simultaneously, we find the equilibrium taxes for signatories and non-signatories.

- For  $\gamma = 1$ :

$$t_i^*(PS, TR) = -\frac{(a-c)(n-2m+1)}{m(n(n-m+1)-m+2)}$$

$$t_j^*(PS, TR) = -\frac{(a-c)(n-1)}{n(n-m+1)-m+2}$$

$$t_i^*(CS, PS, TR) = t_j^*(CS, PS, TR) = -\frac{a-c}{n}$$

$$t_i^*(PS, TR, D) = \frac{\delta(n(m(n-m+3)-n-1)+m(2-m))-(a-c)(n-2m+1)}{m(n(n-m+1)-m+2)}$$

$$t_j^*(PS, TR, D) = -\frac{\delta(m-2)(n+1)+(a-c)(n-1)}{n(n-m+1)-m+2}$$

$$t_i^*(CS, PS, TR, D) =$$

$$\frac{n\delta(m(2-m)+n(n(m-1)+m(3-m)-1))-(a-c)(m(n^2+(1-m)(n+1)))}{mn(n^2+(1-m)(n+1))}$$

$$t_j^*(CS, PS, TR, D) = -\frac{n\delta(m-2)(n+1)+(a-c)(n^2+(1-m)(n+1))}{n(n^2+(1-m)(n+1))}$$

- For  $\gamma = 0$ :

$$t_i^*(PS, TR) = t_j^*(PS, TR) = 0$$

$$t_i^*(CS, PS, TR) = -\frac{(a-c)m}{2n-m}$$

$$t_j^*(CS, PS, TR) = -\frac{a-c}{2n-1}$$

$$t_i^*(PS, TR, D) = \delta m$$

$$t_j^*(PS, TR, D) = \delta$$

$$t_i^*(CS, PS, TR, D) = \frac{(2n\delta - a + c)m}{2n-m}$$

$$t_j^*(CS, PS, TR, D) = \frac{2n\delta - a + c}{2n-1}$$

## 6.2 Definitions

There are certain terms that repeatedly show up in the following. They are listed below.

$$\Psi_1 = n(n-m+1) - m + 2 = n^2 - nm + n - m + 2$$

$$\Psi_2 = n^2 + (1-m)(n+1) = n^2 - nm + n - m + 1$$

$$\Psi_3 = n^2(m-1) - n(m-1)^2 - m(m-2) = n^2m - n^2 - nm^2 + 2nm - n - m^2 + 2m$$

$$\Psi_4 = n(m-1) - m(m-2) = nm - n - m^2 + 2m$$

$$\Psi_5 = (m-2)(n+1) = mn + m - 2n - 2$$

$$\Psi_6 = (m-1)(n+1) = mn + m - n - 1$$

$$\Psi_7 = (n - m)(n - m + 1) - m(1 - m) + 2 = n^2 - 2nm + 2m^2 + n - 2m + 2$$

$$\Psi_8 = n(n^2 + n + 1) - 2nm(n - m + 1) + m^2 = n^3 - 2n^2m + 2nm^2 + n^2 - 2nm + m^2 + n$$

It can be shown that all  $\Psi_k > 0$ ,  $\forall n$  and  $\forall m \leq n$ .

### 6.3 Non-negativity Constraints

Inserting equilibrium taxes into equilibrium output levels, gives the quantities below, from which it is evident that for the first two welfare scenarios no non-negativity constraint needs to be imposed apart from  $a > c$ . For the third and fourth scenarios, additional conditions need to be imposed as explained below.

- For  $\gamma = 1$ :

$$q_{.i}^*(PS, TR) = \frac{(a - c)(n - m + 1)}{m\Psi_1}$$

$$q_{.j}^*(PS, TR) = \frac{n(a - c)}{\Psi_1}$$

$$q_{.i}^*(CS, PS, TR) = q_{.j}^*(CS, PS, TR) = \frac{a - c}{n}$$

$$q_{.i}^*(PS, TR, D) = \frac{(a - c)(n - m + 1) - \delta\Psi_3}{m\Psi_1}$$

$$q_{.j}^*(PS, TR, D) = \frac{n(a - c) + \delta(n(m - 1) + m - 2)}{\Psi_1}$$

$$q_{.i}^*(CS, PS, TR, D) = \frac{(a - c)}{n} - \frac{\Psi_3\delta}{m\Psi_2}$$

$$q_{.j}^*(CS, PS, TR, D) = \frac{(a - c)}{n} + \frac{\delta n(n(m - 1) + m - 2)}{n\Psi_2}$$

- For  $\gamma = 0$ :

$$q_{.i}^*(PS, TR) = q_{.j}^*(PS, TR) = \frac{a - c}{2}$$

$$q_{.i}^*(CS, PS, TR) = \frac{n(a - c)}{2n - m}$$

$$q_{.j}^*(CS, PS, TR) = \frac{n(a - c)}{2n - 1}$$

$$q_{.i}^*(PS, TR, D) = \frac{a - c - \delta m}{2}$$

$$q_{.j}^*(PS, TR, D) = \frac{a - c - \delta}{2}$$

$$q_{.i}^*(CS, PS, TR, D) = \frac{n(a - c - \delta m)}{2n - m}$$

$$q_{.j}^*(CS, PS, TR, D) = \frac{n(a - c - \delta)}{2n - 1}$$

For the third and fourth scenario, the following non-negativity constraints need to be imposed.

- For  $W_i^3 = PS_i + TR_i - D_i$ 
  - For  $\gamma = 1$ : signatories' non-negativity constraint is given by  $a > \tilde{a}_1 = \frac{\delta \Psi_3}{n-m+1} + c$ , and for non-signatories  $a > c$ , with  $\tilde{a}_1 > c$ .
  - For  $\gamma = 0$ : signatories' non-negativity constraint is given by  $a > \tilde{a}_2 = \delta m + c$ , and for non-signatories'  $a > \tilde{a}_3 = \delta + c$ , with  $\tilde{a}_2 > \tilde{a}_3$ .
- For  $W_i^4 = CS_i + PS_i + TR_i - D_i$ 
  - For  $\gamma = 1$ : signatories' non-negativity constraint is given by  $a > \tilde{a}_4 = \frac{\delta n \Psi_3}{m \Psi_2} + c$ , and for non-signatories by  $a > c$ , with  $\tilde{a}_4 > \tilde{a}_2$ .
  - For  $\gamma = 0$ : non-negativity constraints are the same as in the third scenario above ( $a > \tilde{a}_2$  for signatories and  $a > \tilde{a}_3$  for non-signatories).

It is straightforward to show that  $\tilde{a}_1 > \tilde{a}_4$ . Throughout the whole paper, we assume the most restrictive constraint to hold for comparison within a scenario and across scenarios, noting that  $n \geq m \geq 1$ .



## 6.4 Proposition 2 - Comparing Equilibrium Taxes Across Different Welfare Scenarios

Assume  $n \geq m > 2$  and the appropriate non-negativity constraints in section 5.3 to hold. Then, using equilibrium taxes in section 5.1, and the definitions in section 5.2, we find:

For  $\gamma = 1$ :

$$t_i^*(PS, TR) - t_i^*(CS, PS, TR) = \frac{(a-c)(n+1)\Psi_4}{mn\Psi_1} > 0$$

$$t_j^*(PS, TR) - t_j^*(CS, PS, TR) = -\frac{(a-c)\Psi_5}{n\Psi_1} < 0$$

$$t_i^*(PS, TR) - t_i^*(PS, TR, D) = -\frac{\delta(n+1)\Psi_4}{m\Psi_1} < 0$$

$$t_j^*(PS, TR) - t_j^*(PS, TR, D) = \frac{\delta\Psi_5}{\Psi_1} > 0$$

$$t_i^*(PS, TR, D) - t_i^*(CS, PS, TR, D) = \frac{(n+1)\Psi_4}{m\Psi_1} \left( \frac{a-c}{n} - \frac{\delta}{\Psi_2} \right) > 0$$

$$t_j^*(PS, TR, D) - t_j^*(CS, PS, TR, D) = -\frac{(m-2)(n+1)}{\Psi_1} \left( \frac{a-c}{n} - \frac{\delta}{\Psi_2} \right) < 0$$

$$t_i^*(CS, PS, TR) - t_i^*(CS, PS, TR, D) = -\frac{\delta(n+1)\Psi_4}{m\Psi_2} < 0$$

$$t_j^*(CS, PS, TR) - t_j^*(CS, PS, TR, D) = \frac{\delta\Psi_5}{\Psi_2} > 0$$

For  $\gamma = 0$ :

$$t_i^*(PS, TR) - t_i^*(CS, PS, TR) = \frac{(a-c)m}{2n-m} > 0$$

$$t_j^*(PS, TR) - t_j^*(CS, PS, TR) = \frac{a-c}{2n-1} > 0$$

$$t_i^*(PS, TR) - t_i^*(PS, TR, D) = -\delta m < 0$$

$$t_j^*(PS, TR) - t_j^*(PS, TR, D) = -\delta < 0$$

$$t_i^*(PS, TR, D) - t_i^*(CS, PS, TR, D) = \frac{m(a - c - \delta m)}{2n - m} > 0$$

$$t_j^*(PS, TR, D) - t_j^*(CS, PS, TR, D) = \frac{a - c - \delta}{2n - 1} > 0$$

$$t_i^*(CS, PS, TR) - t_i^*(CS, PS, TR, D) = -\frac{2nm\delta}{2n - m} < 0$$

$$t_j^*(CS, PS, TR) - t_j^*(CS, PS, TR, D) = -\frac{2n\delta}{2n - 1} < 0$$

## 6.5 Proposition 3 - Comparing Equilibrium Taxes within each Welfare Scenario

Using equilibrium taxes as listed in section 5.1, and the definitions in section 5.2, we find:

For  $\gamma = 1$ :

$$t_i^*(PS, TR) - t_j^*(PS, TR) = \frac{(a - c)\Psi_6}{m\Psi_1} > 0$$

$$t_i^*(CS, PS, TR) - t_j^*(CS, PS, TR) = 0$$

$$t_i^*(PS, TR, D) - t_j^*(PS, TR, D) = \frac{\Psi_6(n\delta + a - c)}{m\Psi_1} > 0$$

$$t_i^*(CS, PS, TR, D) - t_j^*(CS, PS, TR, C) = \frac{n\delta\Psi_6}{m\Psi_2} > 0$$

For  $\gamma = 0$ :

$$t_i^*(PS, TR) - t_j^*(PS, TR) = 0$$

$$t_i^*(CS, PS, TR) - t_j^*(CS, PS, TR) = -\frac{2n(a - c)(m - 1)}{(2n - m)(2n - 1)} < 0$$

$$t_i^*(PS, TR, D) - t_j^*(PS, TR, D) = \delta(m - 1) > 0$$

$$t_i^*(CS, PS, TR, D) - t_j^*(CS, PS, TR, C) = \frac{2n(2n\delta - a + c)(m - 1)}{(2n - m)(2n - 1)}$$

which is positive if  $\delta m + c < a \leq 2n\delta + c$  (where  $\delta m + c < a$  is the non-negativity constraint) and negative if  $a > 2n\delta + c$ .

Furthermore:

For  $\gamma = 1$ :

$$\frac{\partial t_i^*(PS, TR)}{\partial m} = \frac{(n+1)(a-c)\Psi_7}{m^2\Psi_1^2} > 0$$

$$\frac{\partial t_j^*(PS, TR)}{\partial m} = -\frac{(n+1)(n-1)(a-c)}{\Psi_1^2} < 0$$

$$\frac{\partial t_i^*(CS, PS, TR)}{\partial m} = 0$$

$$\frac{\partial t_j^*(CS, PS, TR)}{\partial m} = 0$$

$$\frac{\partial t_i^*(PS, TR, D)}{\partial m} = \frac{(n+1)(n\delta + a - c)\Psi_7}{m^2\Psi_1^2} > 0$$

$$\frac{\partial t_j^*(PS, TR, D)}{\partial m} = -\frac{(n+1)(n-1)(n\delta + a - c)}{\Psi_1^2} < 0$$

$$\frac{\partial t_i^*(CS, PS, TR, D)}{\partial m} = \frac{\delta(n+1)\Psi_8}{m^2\Psi_2^2} > 0$$

$$\frac{\partial t_j^*(CS, PS, TR, D)}{\partial m} = -\frac{\delta(n+1)(n^2 - n - 1)}{\Psi_2^2} < 0$$

For  $\gamma = 0$ :

$$\frac{\partial t_i^*(PS, TR)}{\partial m} = 0$$

$$\frac{\partial t_j^*(PS, TR)}{\partial m} = 0$$

$$\frac{\partial t_i^*(CS, PS, TR)}{\partial m} = -\frac{2n(a-c)}{(2n-m)^2} < 0$$

$$\frac{\partial t_j^*(CS, PS, TR)}{\partial m} = 0$$

$$\frac{\partial t_i^*(PS, TR, D)}{\partial m} = \delta > 0$$

$$\frac{\partial t_j^*(PS, TR, D)}{\partial m} = 0$$

$$\frac{\partial t_i^*(CS, PS, TR, D)}{\partial m} = \frac{2n(2n\delta - a + c)}{(2n - m)^2}$$

which is positive if  $\delta m + c < a \leq 2n\delta + c$  (where  $\delta m + c < a$  is the non-negativity constraint) and negative if  $a > 2n\delta + c$ .

$$\frac{\partial t_j^*(CS, PS, TR, D)}{\partial m} = 0$$

## 6.6 Proposition 4 - Properties of the Coalition Game<sup>7</sup>

Scenario  $W_i^1 = PS_i + TR_i$ :

- For  $\gamma = 1$ :

$$EP = \frac{(2n^2 - 2nm + 3n - 2m + 5)(n + 1)n^2(a - c)^2}{\Psi_1^2(n^2 - nm + 2n - m + 3)^2} > 0$$

$$SAD =$$

$$- \frac{(n^4 - 2n^3m + n^2m^2 + nm - m^2 - 4n + 3m - 1)(n + 1)(a - c)^2n}{\Psi_1^2(n^2 - nm + 2n - m + 3)^2} > 0, m = n, \& < 0 \forall m < n$$

$$FC = \frac{(n^3 - 2n^2m + nm^2 + 2n^2 - 3nm + m^2 + 3n - 3m + 1)(n + 1)^2(a - c)^2n}{\Psi_1^2(n^2 - nm + 2n - m + 3)^2} > 0$$

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<sup>7</sup>Legend: EP: Externality Property,  $EP = (W_j(m)) - (W_j(m - 1))$ ; SAD: Superadditivity,  $SAD = (\sum_{i \in m} W_i(m)) - (\sum_{i \in (m-1)} W_i(m - 1) + W_j(m - 1))$ ; FC: Full Cohesiveness  $FC = (\sum_{i \in m} W_i(m) + \sum_{j \notin m} W_j(m)) - (\sum_{i \in (m-1)} W_i(m - 1) + \sum_{j \notin (m-1)} W_j(m - 1))$ ; assuming  $n \geq m > 1$ .

- For  $\gamma = 0$ :

$$EP = 0$$

$$SAD = 0$$

$$FC = 0$$

*Scenario*  $W_i^2 = CS_i + PS_i + TR_i$ :

- For  $\gamma = 1$ :

$$EP = 0$$

$$SAD = 0$$

$$FC = 0$$

- For  $\gamma = 0$ :

$$EP = \frac{1}{2} \frac{(32n^3 + m(n(-28n + 8m) - m^2 + m - 1))(m - 1)n^2(a - c)^2}{(2n - 1)^2(2n - m + 1)^2(2n - m)^2} > 0$$

$$SAD = \frac{1}{2} \frac{(4n^2m - 4nm^2 + m^3 + 8nm - 3m^2 - 8n + 3m)(m - 1)n^2(a - c)^2}{(2n - 1)^2(2n - m + 1)^2(2n - m)} > 0$$

$$FC = \frac{1}{2} \frac{(32n^4 - 52n^3m + 24n^2m^2 - 3nm^3)(m - 1)n^2(a - c)^2}{(2n - 1)^2(2n - m + 1)^2(2n - m)^2}$$

$$+ \frac{1}{2} \frac{(16n^2m - 13nm^2 + 2m^3 - 16n^2 + 13nm - 2m^2)(m - 1)n^2(a - c)^2}{(2n - 1)^2(2n - m + 1)^2(2n - m)^2} > 0$$

*Scenario*  $W_i^3 = PS_i + TR_i - D_i$ :

- For  $\gamma = 1$ :

$$EP = \frac{(n\delta + a - c)^2(2n^2 - 2nm + 3n - 2m + 5)(n + 1)n^2}{\Psi_1^2(n^2 - nm + 2n - m + 3)^2} > 0$$

$$SAD =$$

$$-\frac{(n\delta + a - c)^2(n^4 - 2n^3m + n^2m^2 + nm)(n + 1)n}{\Psi_1^2(n^2 - nm + 2n - m + 3)^2}$$

$$-\frac{(n\delta + a - c)^2(-m^2 - 4n + 3m - 1)(n + 1)n}{\Psi_1^2(n^2 - nm + 2n - m + 3)^2} > 0, m = n, \& < 0 \forall m < n$$

$$FC = \frac{(n\delta + a - c)^2(n^3 - 2n^2m + nm^2 + 2n^2 - 3nm + m^2 + 3n - 3m + 1)(n + 1)^2n}{\Psi_1^2(n^2 - nm + 2n - m + 3)^2} > 0$$

- For  $\gamma = 0$ :

$$EP = n(m - 1)\delta^2 > 0$$

$$SAD = \frac{1}{4}n(m - 1)m\delta^2 > 0$$

$$FC = \frac{1}{4}n(m - 1)(4n - 3m)\delta^2 > 0$$

Scenario  $W_i^4 = CS_i + PS_i + TR_i - D_i$ :

- For  $\gamma = 1$ :

$$EP = \frac{1}{2} \frac{\delta^2(2n^2 - 1)(2n^2 - 2nm + 3n - 2m + 3)(n + 1)n^2}{(n^2 - \Psi_5)^2\Psi_2^2} > 0$$

$$SAD = -\frac{1}{2} \frac{\delta^2(2n^5 - 4n^4m + 2n^3m^2 - 4n^3 + 8n^2m)(n + 1)n^2}{(n^2 - \Psi_5)^2\Psi_2^2} -$$

$$\frac{1}{2} \frac{\delta^2(-4nm^2 - 8n^2 + 9nm - 2m^2 - 4n + 3m)(n + 1)n^2}{(n^2 - \Psi_5)^2\Psi_2^2} > 0, m = n, \& < 0, \forall m < n$$

$$FC = \frac{1}{2} \frac{\delta^2(2n^3 - 4n^2m + 2nm^2 + 4n^2 - 6nm + 2m^2 + 4n - 4m + 1)(n + 1)^2n^3}{(n^2 - \Psi_5)^2\Psi_2^2} > 0$$

- For  $\gamma = 0$ :

$$EP = \frac{1}{2} \frac{(n\delta - a + c)^2(32n^3 - 28n^2m + 8nm^2 - m^3 + m^2 - m)(m - 1)n^2}{(2n - 1)^2(2n - m + 1)^2(2n - m)^2} > 0$$

$$SAD = \frac{1}{2} \frac{(n\delta - a + c)^2(4n^2m - 4nm^2 + m^3 + 8nm - 3m^2 - 8n + 3m)(m - 1)n^2}{(2n - 1)^2(2n - m + 1)^2(2n - m)^2} > 0$$

$$FC =$$

$$\frac{1}{2} \frac{(n\delta - a + c)^2(32n^4 - 52n^3m + 24n^2m^2 - 3nm^3)(m - 1)n^2}{(2n - 1)^2(2n - m + 1)^2(2n - m)^2} +$$

$$\frac{1}{2} \frac{(n\delta - a + c)^2(16n^2m - 13nm^2 + 2m^3 - 16n^2 + 13nm - 2m^2)(m - 1)n^2}{(2n - 1)^2(2n - m + 1)^2(2n - m)^2} > 0$$

## 6.7 Proposition 5 - Coalition Stability

Scenario  $W_i^1 = PS_i + TR_i$ :

- For  $\gamma = 1$

$$W_i(S) - W_i(S \setminus \{i\}) = - \frac{n(a - c)^2(n + 1)(n^4m - 2n^3m^2 + n^2m^3 - n^4 + 4n^3m - 5n^2m^2 + 2nm^3)}{m\Psi_1^2(n^2 - nm + 2n - m + 3)^2} -$$

$$\frac{n(a - c)^2(n + 1)(-4n^3 + 13n^2m - 10nm^2 + m^3 - 10n^2 + 17nm - 7m^2 - 12n + 15m - 9)}{m\Psi_1^2(n^2 - nm + 2n - m + 3)^2} < 0$$

- For  $\gamma = 0$ :

$$W_i(S) - W_i(S \setminus \{i\}) = 0$$

Scenario  $W_i^2 = CS_i + PS_i + TR_i$ :

- For  $\gamma = 1$ :

$$W_i(S) - W_i(S \setminus \{i\}) = 0$$

- For  $\gamma = 0$ :

$$W_i(S) - W_i(S \setminus \{i\}) =$$

$$-\frac{1}{2} \frac{n^2(a-c)^2(m-1)(2nm-m^2-6n+3m-1)}{(2n-1)(2n-m+1)^2(2n-m)} > 0, \forall m \leq 3, \text{ \& } < 0, \forall m > 3$$

*Scenario*  $W_i^3 = PS_i + TR_i - D_i$ :

- For  $\gamma = 1$

$$\begin{aligned} W_i(S) - W_i(S \setminus \{i\}) &= -\frac{n(n\delta + a - c)^2(n+1)(n^4m - 2n^3m^2 + n^2m^3 - n^4 + 4n^3m)}{m\Psi_1^2(n^2 - nm + 2n - m + 3)^2} - \\ &\quad \frac{n(n\delta + a - c)^2(n+1)(-5n^2m^2 + 2nm^3 - 4n^3 + 13n^2m - 10nm^2)}{m\Psi_1^2(n^2 - nm + 2n - m + 3)^2} - \\ &\quad \frac{n(n\delta + a - c)^2(n+1)(m^3 - 10n^2 + 17nm - 7m^2 - 12n + 15m - 9)}{m\Psi_1^2(n^2 - nm + 2n - m + 3)^2} < 0 \end{aligned}$$

- For  $\gamma = 0$ :

$$W_i(S) - W_i(S \setminus \{i\}) = -\frac{1}{4}n\delta^2(m-1)(m-3) \geq 0, \forall m \leq 3, \text{ \& } < 0, \forall m > 3$$

*Scenario*  $W_i^4 = CS_i + PS_i + TR_i - D_i$ :

- For  $\gamma = 1$ :

$$\begin{aligned} W_i(S) - W_i(S \setminus \{i\}) &= -\frac{1}{2} \frac{\delta^2 n^2 (n+1) (2n^5 m - 4n^4 m^2 + 2n^3 m^3 - 2n^5 + 8n^4 m - 10n^3 m^2)}{m\Psi_2^2(n^2 - \Psi_5)^2} - \\ &\quad \frac{1}{2} \frac{\delta^2 n^2 (n+1) (4n^2 m^3 - 8n^4 + 22n^3 m - 16n^2 m^2 + 2nm^3 - 16n^3)}{m\Psi_2^2(n^2 - \Psi_5)^2} - \\ &\quad \frac{1}{2} \frac{\delta^2 n^2 (n+1) (28n^2 m - 12nm^2 - 16n^2 + 19nm - 2m^2 - 8n + 3m)}{m\Psi_2^2(n^2 - \Psi_5)^2} < 0 \end{aligned}$$

- For  $\gamma = 0$ :

$$W_i(S) - W_i(S \setminus \{i\}) =$$

$$-\frac{1}{2} \frac{n^2(2n\delta - a + c)^2(m-1)(2nm-m^2-6n+3m-1)}{(2n-1)(2n-m+1)^2(2n-m)} > 0, \forall m \leq 3, \text{ \& } < 0, \forall m > 3$$



## Part VI

# Paper 2: Measures to Enhance the Effectiveness of International Climate Agreements: The Case of Border Tax Adjustments


**Statement of Authorship** (to preface each co-authored paper)

<b>This declaration concerns the article entitled:</b>			
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<b>Candidate's contribution to the paper (detailed, and also given as a percentage).</b>	<p>The candidate contributed to/ considerably contributed to/predominantly executed the...</p> <p>Formulation of ideas:</p> <ul style="list-style-type: none"> <li>- Considerably contributed to the formulation of ideas. (50%)</li> </ul> <p>Design of methodology:</p> <ul style="list-style-type: none"> <li>- Predominantly contributed to the design of methodology. (65%)</li> </ul> <p><del>Experimental work:</del></p> <p>Presentation of data in journal format:</p> <ul style="list-style-type: none"> <li>- Predominantly contributed to the presentation of data in journal format. (70%)</li> </ul>		
<b>Statement from Candidate</b>	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature.		
<b>Signed</b>	Alaa Al Khourdajie		<b>Date</b> 02/03/2017

# Measures to Enhance the Effectiveness of International Climate Agreements: The Case of Border Tax Adjustments

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(Preliminary Version - please do not quote)

## Abstract

Unilateral or sub-global actions on climate change are not very effective but global action is not stable due to strong free-rider incentives. These incentives arise because of emissions leakage by non-signatories and the loss of competitiveness by treaty signatories due to higher environmental standards. We study a policy instrument which has been recently proposed to tackle free-riding: border tax adjustments (BTAs). We use a simple strategic trade model which captures consumers' taste for variety to analyse the conditions when BTAs are able to level the playing field and lead to large stable environmental treaties. We show they are particularly successful provided treaties remain of the open membership type and do not serve the interests of few countries who may prefer an exclusive membership rule.

Keywords: self-enforcing international environmental agreements, international trade, border tax adjustments, consumers' preferences, horizontal products' differentiation.

JEL Classification: C72, F18, H23, Q52, Q54, Q56, Q58.

# 1 Introduction

Reaching international agreements on climate change has proved to be a difficult task over the past two and half decades. One of the most notable achievements of the climate change negotiations thus far is Paris Climate Agreement, signed in December 2015. This agreement aims to achieve the scientifically recommended target of limiting the temperature increase by the year 2100 to 2 degrees Celsius compared to pre-industrial levels. However, despite agreeing on this target, signatories' current emission reduction pledges fall short of meeting it and will potentially yield a temperature increase of 2.7-3 degrees Celsius (UNFCCC, 2015). Furthermore, the agreement fails to bind signatories to meet their pledges.

Scholars in the game theoretic literature on the formation of international environmental agreements (IEAs) attribute the difficulty in reaching an effective climate change agreement to strong free-riding incentives. These incentives emerge due to the fact that any non-signatory would enjoy the environmental benefits resulting from signatories' emissions reduction efforts without incurring any costs. Therefore, given the absence of supranational authority that could enforce cooperation on climate change, any stable agreement has to be self-enforcing. Findings in this literature show that this free riding phenomenon has either led to agreements with few signatories and/or with very low and hence ineffective emission reduction targets. In other words, these agreements are either small, shallow or both (see Barrett, 1994a; and Finus, 2003 for surveys).

In the context of international trade and free movement of goods and factors of production there are additional challenges facing effective action on climate change. Unilateral or sub-global actions on climate change could lead to a shift in production towards non-signatory countries resulting in emission leakage. Furthermore, firms operating in signatory countries suffer from loss of competitiveness due to the costs of complying with the climate policy. In other words, when considering international trade, incentives for coordinating (free riding on) climate change actions are weaker (stronger) than the case of autarky. Check Zhang (2012) for a survey on the theoretic literature and empirical evidence.

This paper is an extension of Finus and Al Khourdajie (2017) in which the authors introduce horizontal products' differentiation and consumers' taste for variety (TFV) to the literature of IEAs under free trade. The authors find that only with a sufficiently high taste for variety, free riding incentives are sufficiently mitigated such that small agreements are stable. In other words, their findings confirm the pessimistic conclusion which mainly emerges from the IEA literature, and hence emission taxes as first best solution did not help in reaching the grand coalition.

In order to overcome such pessimistic predictions, further contributions in the literature followed different strategies such as analysing various policy instruments, markets' structures or trade features. In this paper we analyse the effects of instrumenting the IEA agreement with a trade policy called border tax adjustment (BTA)

as a second best solution. Using this policy signatory governments can impose an additional border tax on imports from non-signatories' firms. This border tax amounts to the tax differential between the high emission tax that signatory firms are facing in their domestic markets and the low emission tax that non-signatory firms are facing for their exports to these markets.

There are other trade policy instruments that could be employed to improve the incentives for cooperation on climate change. One option could be trade tariffs, which government can impose on imports. The main differences between the BTA policy and trade tariffs are as follows. Firstly, BTAs are policy instruments available to signatory governments only. They are justified on the bases that only when signatories choose higher emission taxes than non-signatories they can impose BTAs on imports from non-signatories' firms. This will allow signatory governments to level the playing field in their own markets as well as create additional and explicit incentives to join the environmental agreement. As for trade tariffs, they are available to all governments of all countries, be it signatory or non-signatory ones. Tariffs in this context are employed as a trade policy instrument. They are widely adopted worldwide as part of the existing international trade system. One could explore whether signatory governments can benefit from such existing policies to influence participation in climate change agreements. The second difference between BTAs and trade tariffs is as follows. BTAs are limited to the difference between signatories' emission taxes and non-signatories' one. Whereas, trade tariffs are not constrained to any rule. The level of signatories' tariffs is chosen to maximise their joint welfare.

In the current literature on BTAs, contributions use a 2-country setup extending Brander and Spencer (1985) framework of Cournot oligopoly. Most contributions in this literature show that BTA schemes are Pareto improving, lead to higher emission taxes as well as higher participation in effective IEAs (Vlassis, 2014; Eyland and Zaccour, 2013 and 2014; and Anoulies, 2014). Also following B&S (1985) setup, Baksi and Chaudhuri (2016) assume infinitely repeated games framework and find that BTAs might discourage cooperation for countries with high emission taxes whenever the discounted gains from the BTAs revenues are larger than the negative effects of high emissions. Baksi and Chaudhuri (2014) examine the application of BTAs in an  $n$  country model and show that introducing BTAs leads to higher global welfare when the grand coalition is not stable. Our paper contributes to this body of literature by analysing the effects of consumers' TFV under imperfect competition in an  $n$  country framework.

Another strand in the literature focuses on estimating the effects of BTAs using computable general equilibrium (CGE) models. Branger and Quirion (2014) conduct a comprehensive meta-analysis on 25 relevant studies (including Böhringer et al. 2012; and Fischer and Fox, 2012) and show that findings in all these studies support the argument that BTAs lead to a decrease in emission leakage. Applying the BTA case on the Canadian economy, Dissou and Eyland (2011) find that BTAs reduce the competitive disadvantage that domestic industries suffer from given the high

production costs due to emission taxes. The main setback of these CGE studies is they discount the possibility of allowing other countries to react to BTAs through adjusting their domestic emission reduction policies. However, Irfanoglu et al. (2015) overcome this setback and combine a sequential game and CGE model to study the case of imposing BTAs by the United States against China. The authors find that BTAs lead to compliance by China with the socially optimal taxes.

Our paper also relates to the literature that assesses the conditions under which larger and more effective IEAs could form under international trade comparing to autarky. Extending Barrett's (1994b) IEAs autarky model to the case of international trade under perfect competition, Eichner and Pethig (2013) show that large coalitions could be stable under Stackelberge coalition formation games comparing to small coalitions under Nash Cournot games as in E&P (2012). However, they find that the emission reduction efforts of these large coalitions are negligible. In E&P (2014a) the authors show that the introduction of emissions taxes could lead to the stability of the grand coalition. Other contributions in this literature strand address the implications of using trade bans as an additional policy instrument in the climate agreement and show that such policy leads to large and more effective agreements (Barrett, 1997; and E&P, 2014b).

Our model is an extension of Brander and Spencer (1985) framework where we assume *n ex ante* symmetric countries, the governments of which are concerned not only with their firms' profits and tax revenues but also with the utility of their consumers and environmental damages resulting from a global pollutant. Each country has a single firm that produces a unique variety of a horizontally differentiated good and consumers' have taste for these varieties. Thus, our paper benefits from contributions by Yi (1996) and (2000) who look at international trade, trade agreements and taste for variety, but ignore environmental damages and their effect on governments' strategic behaviour.<sup>8</sup>

Governments in each country can impose emissions tax on their firm's production in order to reduce pollution damages. Countries that join the climate change agreement are able to impose border tax adjustments on imports from non-signatories' firms. Revenues from these border taxes represent an additional income for signatories' governments. In this setup we examine the effects of border tax adjustment in influencing countries' decisions on their emission taxes as well as membership status by comparing two cases: climate change agreements with and without border tax adjustments, called hereafter: BTA regime and No BTA regime, respectively.

Our results show that when consumers have low or medium taste for varieties, the BTA regime leads to the grand coalition to be stable if membership is open to all countries. When consumers have high taste for varieties, the grand coalition is destabilised under open membership. The paper proceeds as follows. In section 2 we

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<sup>8</sup>Check Loke and Winters (2012) for detailed analysis of the TFV feature in the context of Yi's papers.

present the model. In section 3 we present the results with detailed discussion about their driving forces. In section 4 we conclude.

## 2 Model

### 2.1 Payoff Function

Consider an intra-industry trade model of  $n$  *ex ante* symmetric countries with a representative firm and consumer in each country. We denote the set of countries by  $N$ . Firms produce a horizontally differentiated good, i.e. the same good but in different varieties where each firm produces one unique variety. Firms compete in a Cournot-fashion. Markets are segmented and each firm supplies its good to the domestic and all foreign markets. Because of the segmentation of markets, firms play a separate Cournot game in each market.<sup>9</sup> Transport costs are assumed away as usual.

Analysing the BTA policy is only applicable in the case of partial cooperation. More specifically, suppose a coalition  $S$  forms, with  $m$  the cardinality of  $S$ . In order to analyse the BTA policy, called the “BTA regime”, we focus on  $m = [2, n - 1]$ , i.e. partial cooperation where there is set of signatory countries that impose BTAs on imports from firms located in non-signatory countries. Signatories are denoted by  $i$  ( $i \in S$  set of signatories), and non-signatories are denoted by  $j$  ( $j \in N \setminus S$  set of non-signatories). The BTA policy plays no role in the singletons coalition structure and the grand coalition (i.e.  $m = \{1, n\}$ , respectively). However, in some part of the paper we undertake analysis for the whole range  $m = [1, n]$ , in which case we refer to the analysis of Finus and Al Khourdajie (2017), called the “No BTA” regime. We also undertake comparative analysis between the BTA and No BTA regimes.

The welfare of a signatory country  $i \in S$  is given by:

$$W_i = CS_i + PS_i + BTR_i + TR_i - D_i \quad (1)$$

where  $CS_i$  represents country  $i$ 's consumer surplus,  $PS_i$  country  $i$ 's producer surplus,  $BTR_i$  country  $i$ 's tax revenue from border tax adjustments imposed by the domestic government on imports from non-signatories' firms,  $TR_i$  country  $i$ 's emission tax revenue from the tax imposed by the government on its domestic firm production, and finally  $D_i$  is the pollution damages faced by country  $i$ .

The welfare of a non-signatory country  $j \in N \setminus S$  is given by:

$$W_j = CS_j + PS_j + TR_j - D_j \quad (2)$$

each term represents the same welfare component as in equation (1) after the appropriate changes in notations. Note that a non-signatory government will not be able to impose a border tax adjustment on imports from other countries' firms.

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<sup>9</sup>See Appleyard and Field (2014) as well as Helpman and Krugman (1985) for further background.

In what follows some of the functions for the welfare components are identical between signatories and non-signatories and hence we will present the signatories' ones only.

Consumers are identical and their preferences are represented by a quasi-linear utility function over two goods (see equation (3) below). The first good is the horizontally differentiated and traded good. The second good is a numeraire good, representing the composition of all other goods. Utility is linear in the numeraire good and quadratic in the differentiated good.

We assume that consumers have a taste for variety (Dixit and Stiglitz, 1977). That is, their utility depends not only on the total quantity consumed but also on the composition of quantities of the differentiated good (Yi, 1996 and 2000). The taste for variety (abbreviated TFV hereafter) is captured by parameter  $\gamma \in [0, 1]$ . High values of  $\gamma$  imply a low taste for variety and for  $\gamma = 1$  varieties are perfect substitutes. In contrast, low values of  $\gamma$  represent a high preference for a diverse and balanced consumption bundle and for  $\gamma = 0$  varieties cannot be substituted at all.<sup>10</sup>

More specifically, let the representative consumer's utility in a signatory country  $i$  be given by  $u_i$ :

$$u_i(q_i; M_i) = v_i(q_i) + M_i = aQ_i - \frac{\gamma}{2}Q_i^2 - \frac{1-\gamma}{2} \sum_{k \in N} q_{ik}^2 + M_i \quad (3)$$

where  $v_i$  represents the utility from consuming the horizontally differentiated and traded good and  $M_i$  represents the utility from consuming the numeraire good;  $q_i = (q_{i1}, \dots, q_{in})$  is a vector of the varieties consumed by consumers in country  $i$  that are produced by all signatories' and non-signatories' firms, with  $q_{ik}$  representing country  $i$ 's consumption of country  $k$ 's variety;<sup>11</sup>  $a$  is a positive demand parameter and  $Q_i = \sum_{k \in N} q_{ik}$  is country  $i$ 's total consumption of all varieties, supplied by all countries  $k$  (i.e. signatory and non-signatory countries).

In this paper, in most parts, we will focus our analysis on three TFV cases for analytic tractability: no TFV with  $\gamma = 1$ , partial TFV with  $\gamma = 0.5$  and full TFV with  $\gamma = 0$ .

From (3), country  $i$ 's inverse demand function for country  $k$ 's variety follows from:

$$p_{ik} = \frac{\partial u_i}{\partial q_{ik}} \iff p_{ik} = a - (1 - \gamma)q_{ik} - \gamma Q_i \iff p_{ik} = a - q_{ik} - \gamma \sum_{l \in N, l \neq k} q_{il} \quad (4)$$

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<sup>10</sup>An extension could be the "ideal variety" approach where consumers have not only a general preference for the variety of a good but also a preference for a particular variety. One application is a bias towards the domestically produced variety (Di Comite *et al*, 2014).

<sup>11</sup>Throughout the paper the first subscript indicates the market in which the variety is consumed and the second subscript indicates the market in which it is produced.



where  $p_{ik}$  represents the price faced by consumers in country  $i$  consuming the variety of country  $k$  and  $\sum_{l \in N, l \neq k} q_{il}$  is the sum of all consumed varieties produced by all firms except firm  $k$  in country  $i$ .

From (3) and (4), the representative consumer surplus in a signatory country  $i \in S$  is given by:

$$CS_i = aQ_i - \frac{\gamma}{2}Q_i^2 - \frac{1-\gamma}{2} \sum_{k \in N} q_{ik}^2 - \sum_{k \in N} q_{ik}p_{ik} \quad (5)$$

where the last term in (5) represents consumers' spending.

The emission tax revenue for a signatory country  $i \in S$  is given by:

$$TR_i = t_i \sum_{k \in N} q_{ki} \quad (6)$$

The emission tax revenue for a non-signatory country  $j \in N \setminus S$  is given by:

$$TR_j = t_j \sum_{k \in N} q_{kj} \quad (7)$$

Equation (7) reaffirms the idea that each non-signatory government taxes the total output of its domestic firm irrespective of the destination market to which this output is being produced.

The damages from global pollution faced by a signatory country  $i \in S$  are given by:

$$D_i = \delta \sum_{k \in N} Q_k. \quad (8)$$

where  $\delta$  is a damage parameter,  $\sum_{i \in N} Q_k$  is total consumption in every country  $k$  and hence total emissions (due to our assumption of a constant emission output coefficient of 1). That is, emissions constitute a pure public bad: damages depend on total emissions.

For producers, allowing for the possibility of border tax adjustments, we need to distinguish between firms located in signatory and non-signatory countries. The producer surplus of a firm located in signatory country  $i$  is the sum of its profit obtained in each market: the

$$PS_i = \sum_{k \in S} \pi_{ki} + \sum_{l \in N \setminus S} \pi_{li} = \sum_{k \in S} q_{ki}(p_{ki} - c - t_i) + \sum_{l \in N \setminus S} q_{li}(p_{li} - c - t_i) \quad (9)$$

where  $\pi_{ki}$  ( $\pi_{li}$ ) represents firm  $i$ 's profit in signatory  $k$ 's (non-signatory  $l$ 's) market from selling quantity  $q_{ki}$  ( $q_{li}$ ) at price  $p_{ki}$  ( $p_{li}$ );  $c$  is constant marginal cost and  $t_i$  is the tax imposed by country  $i$ 's government on its firm's production.

Producer surplus for a non-signatory  $j$ 's firm is the sum of its profit in each market:

$$PS_j = \sum_{k \in S} \pi_{kj} + \sum_{l \in N \setminus S} \pi_{lj} = \sum_{k \in S} q_{kj}(p_{kj} - c - t_j - \Omega) + \sum_{l \in N \setminus S} q_{lj}(p_{lj} - c - t_j) \quad (10)$$

where  $\pi_{kj}$  ( $\pi_{lj}$ ) represents firm  $j$ 's profit in signatory  $k$ 's (non-signatory  $l$ 's) market from selling quantity  $q_{kj}$  ( $q_{lj}$ ) at price  $p_{kj}$  ( $p_{lj}$ ), and  $t_j$  is the tax imposed by country  $j$ 's government on its firm's production.

$\Omega$  in equation (10) captures the border tax adjustment that firm  $j$  faces when it exports its variety to a signatory market  $i$ . For the BTA policy to be valid, signatories' emission tax  $t_i$  must be greater than non-signatories' emission tax  $t_j$  (i.e.  $t_i > t_j$ ), so that a positive BTA is imposed on the border of signatories' markets. We call this condition the BTA constraint. If the BTA constraint is violated (i.e.  $t_i \leq t_j$ ) then the border tax adjustment turns into a border subsidy and hence the BTA analysis in our context is not valid.

Using  $\Omega$  we ensure that the BTA constraint is satisfied as follows.  $\Omega$  is a piecewise

function such that  $\Omega = \begin{cases} \phi(t_i - t_j) & \text{if } t_i > t_j \\ 0 & \text{if } t_i \leq t_j \end{cases}$ . The first case,  $\Omega = \phi(t_i - t_j)$ ,

represents the border tax adjustment that is applicable only when the BTA constraint is satisfied, i.e.  $t_i > t_j$ . The BTA parameter  $\phi > 0$  indicates the adjustment level.<sup>12</sup> We impose full adjustment where  $\phi = 1$  so that signatories would generate the highest border tax adjustment revenue by taxing the full difference between  $t_i$  and  $t_j$ . Furthermore, full adjustment would also fully level the playing field for all firms operating in each signatory's market. We do not analyse the case of  $\phi > 1$  as it would be difficult to justify this against the rules of the World Trade Organisation (WTO).

Notice that under full adjustment (i.e. plugging  $\Omega = \phi(t_i - t_j)$  and  $\phi = 1$  in equation (10) above) non-signatories' firms are de facto facing  $t_i$  in total when they export their variety to signatories' markets. However, given the specification in (10), non-signatories' firms face  $t_j$  at home imposed by their own government on all production irrespective of the destination market, and when they export to signatories' markets they additionally face the difference  $(t_i - t_j)$  due to the BTA, bringing the total tax burden they face for their production to signatories' markets to  $t_i$ . The second case of the piecewise function,  $\Omega = 0$ , represents the situation where the BTA constraint is not satisfied, i.e.  $t_i \leq t_j$ .

The revenue from the border tax adjustments imposed by a signatory country  $i \in S$  on imports from a non-signatory's firm  $j$  is given by  $BTR_i$ :

$$BTR_i = \Omega \sum_{j \in N \setminus S} q_{ij} \quad (11)$$

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<sup>12</sup>Following Eyland and Zaccour (2013).

$\Omega$  follows the same rational as above. Equation (11) ensures that signatories are able to collect border tax revenue from the difference of  $(t_i - t_j)$  only.

## 2.2 Coalition Formation Game

We assume a three-stage coalition formation game, which unfolds as follows when solved by backward induction.

*Stage 3, Choice of Output:* all firms choose simultaneously and non-cooperatively their segmented market outputs by maximising their producer surplus:  $\max_{q_{1i}, \dots, q_{ni}} PS_i$

*Stage 2, Choice of Policy Level:* all countries choose simultaneously their emission tax.

- Signatories choose their joint emission tax  $t_i$  (implemented uniformly in all signatory countries) in order to maximise the joint welfare of coalition  $S$ :  $\max_{t_i} \sum_{i \in S} W_i$
- Non-signatories choose their individual tax  $t_j$  in order to maximise their individual welfare:  $\max_{t_j} W_j$

*Stage 1, Choice of Membership:* all countries decide simultaneously whether to join a coalition  $S$  with  $m$  the cardinality of  $S$ . Countries which do not join  $S$  act as singletons. A typical signatory will be denoted by  $i$  and a non-signatory by  $j$ .

A coalition is called stable following d'Aspremont et al. (1983) if it is internally and externally stable (I&ES). Internal stability means that no signatory has an incentive to leave coalition  $S$ , whereas external stability means that no non-signatory has an incentive to join coalition  $S$ . We assume for simplicity that in the case of indifference a non-signatory joins coalition  $S$ .

Internal stability:

$$W_i(S) - W_i(S \setminus \{i\}) \geq 0 \quad \forall i \in S$$

External stability:

$$W_j(S) - W_j(S \cup \{j\}) > 0 \quad \forall j \in N \setminus S$$

## 2.3 Properties of the Game

We define the following properties to analyse the incentive structure to form coalitions and the associated welfare implications.

For all  $S \subset N$ ,  $S \neq \emptyset$ , and  $S' = S \cup \{j\}$  where  $S' \subseteq N$ :

- **Positive Externality:** in a coalition game a move from coalition  $S$  to coalition  $S'$  exhibits a (strict) positive externality if:

$$W_j(S') \geq (>) W_j(S) \quad \forall j \notin S \text{ and } j \notin S'$$

- **Negative Externality:** in a coalition game a move from coalition  $S$  to coalition  $S'$  exhibits a strict negative externality if:

three

$$W_j(S') < W_j(S) \quad \forall j \notin S \text{ and } j \notin S'$$

- **Positive Internal Spillover:** in a coalition game a move from coalition  $S$  to coalition  $S'$  exhibits (strict) positive internal spillovers if:

$$W_i(S') \geq (>) W_i(S) \quad \forall i \in S \text{ and } i \in S'$$

- **Negative Internal Spillover:** in a coalition game a move from coalition  $S$  to coalition  $S'$  exhibits strict negative internal spillovers if:

the

$$W_i(S') < W_i(S) \quad \forall i \in S \text{ and } i \in S'$$

- **Superadditivity:** in a coalition game a move from coalition  $S$  to coalition  $S'$  is (strictly) superadditive if:

$$\sum_{i \in S'} W_i(S') \geq (>) \sum_{i \in S} W_i(S) + W_j(S)$$

- **Cohesiveness:** a coalition game is (strictly) cohesive if:

$$\sum_{i \in N} W_i(N) \geq (>) \sum_{i \in S} W_i(S) + \sum_{j \in N \setminus S} W_j(S)$$

- **Full Cohesiveness:** in a coalition game a move from coalition  $S$  to coalition  $S'$  is (strictly) fully cohesive if:

$$\sum_{i \in S'} W_i(S') + \sum_{j \in N \setminus S'} W_j(S') \geq (>) \sum_{i \in S} W_i(S) + \sum_{j \in N \setminus S} W_j(S)$$

Superadditivity provides the incentives to join a coalition, whereas the positive externality captures the incentive to free ride. In terms of forming large stable coalitions, the two properties work in opposite directions and typically for large coalitions the positive externality effects should be dominated by the superadditivity effects. We introduce two new properties, namely positive and negative internal spillovers that represent the effects of enlarging the coalition on the current signatories individually. We characterise the relationship between the internal spillover (positive and negative) and superadditivity properties in Appendix 1. Full cohesiveness justifies the search for large stable coalitions, even if the grand coalition is not stable. Essentially, global welfare increases when the coalition is enlarged gradually and if it obtains its maximum under the grand coalition then cohesiveness holds.

## 3 Results

### 3.1 Third Stage

In this section, we derive the results for the third stage. In the case of cooperation, if we already account for the fact of symmetric taxes in stage 2 with all signatories choosing the same tax rate  $t_i$  and all non-signatories choose the same tax rate  $t_j$  (and typically  $t_i \neq t_j$ ), we can derive the equilibrium quantity for a signatory's and a non-signatory's firm as follows.

Given the segmented markets' structure, markets can be categorised into signatories' and non-signatories' markets. First we look at markets under the BTA regime. In a signatory's market, there are two equilibrium quantities. The first  $q_{ki}^*$  represents signatory firm  $i$ 's production to any signatory's market  $k$ . This firm faces an emission tax only, imposed by its own government. The second equilibrium quantity  $q_{kj}^*$  represents non-signatory firm  $j$ 's production to any signatory's market  $k$ . This firm faces an emission tax imposed by its own government, and the BTA adjustment imposed by the signatory's government of the destination market. The total consumption in any signatory's market is given by  $Q_k^*$ .<sup>13</sup> As for non-signatories' markets, there are also two equilibrium quantities. The first  $q_{li}^*$  represents signatory firm  $i$ 's production to any non-signatory's market  $l$ . This firm faces an emission tax only, imposed by its own government. The second equilibrium quantity  $q_{lj}^*$  represents non-signatory firm  $j$ 's production to any non-signatory's market  $l$ . This firm faces an emission tax only, imposed by its own government. The total consumption in any non-signatory's

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<sup>13</sup>Notation: in total consumption we replace the second subscript with a dot (e.g.  $Q_k^*$ ) in order to illustrate summing total consumption irrespective of the production source. The same principle applies to total production as illustrated in the BTA Regime table.

market is given by  $Q_{li}^*$ . The segmented market structure under the BTA regime can be illustrated in the following table:

<b>BTA Regime</b>	Signatory firm $i$	Non-signatory firm $j$	Total Consumption
Signatory market $k$	$q_{ki}^*$	$q_{kj}^*$	$Q_k^*$
Non-signatory market $l$	$q_{li}^*$	$q_{lj}^*$	$Q_l^*$
Total Production	$Q_{.i}^*$	$Q_{.j}^*$	$Q$

We now look at markets under the No-BTA regime. Given our assumption of segmented market structure each firm supplies its good to the domestic and all foreign markets. Since the tax imposed on production is not differentiated based on the destination market and there are no BTA adjustments in the No BTA regime, the equilibrium quantity of any firm's variety is the same for all markets. That is, because of the segmentation of markets firms play a separate and identical Cournot game in each market. Therefore, there are two equilibrium quantities in the No BTA regime irrespective of the destination market. The first  $q_i^*$  represents signatory firm  $i$ 's production to any market.<sup>14</sup> This firm faces an emission tax only, imposed by its own government. The second equilibrium quantity  $q_j^*$  represents non-signatory firm  $j$ 's production to any market. This firm faces an emission tax only, imposed by its own government. The segmented market structure under the No BTA regime can be illustrated in the following table:

<b>No BTA Regime</b>	Signatory firm $i$	Non-signatory firm $j$	Total Consumption
Signatory market $k$	$q_i^*$	$q_j^*$	$mq_i^* + (n - m)q_j^*$
Non-signatory market $l$			
Total Production	$nq_i^*$	$nq_j^*$	$n(mq_i^* + (n - m)q_j^*)$

Looking at the BTA regime, we first present the equilibrium quantities for all firms' varieties produced for a non-signatory's market ( $q_{li}^*$  &  $q_{lj}^*$ ). These equilibrium quantities ( $q_{li}^*$  &  $q_{lj}^*$ ) have the same functional form of the No BTA regime's equilibrium quantities ( $q_i^*$  &  $q_j^*$ ), respectively. This is true because there are no BTA adjustments in non-signatories' markets under the BTA regime, and of course no BTA adjustments in the No BTA regime. However, once the equilibrium taxes are inserted into quantities, then the actual quantities will be different. Therefore, we do not need to derive  $q_i^*$  and  $q_j^*$  as they will follow the same functional forms as  $q_{li}^*$  and  $q_{lj}^*$ , respectively. We present the detailed quantities' derivation in Appendix 2.

A signatory firm  $i$ 's variety produced for a non-signatory  $l$ 's market is given by:

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<sup>14</sup>Notation: we replace the first subscript with a dot in order to illustrate the idea that a signatory's firm produces the same output irrespective of the destination market. Same applies for a non-signatory's firm, as we will show next.

$$q_{li}^* = \frac{(a-c)(2-\gamma) - \gamma(n-m)(t_i - t_j) - t_i(2-\gamma)}{((n-1)\gamma + 2)(2-\gamma)} \quad (12)$$

and a non-signatory firm  $j$ 's variety produced for a non-signatory  $l$ 's market is given by:

$$q_{lj}^* = \frac{(a-c)(2-\gamma) + \gamma m(t_i - t_j) - t_j(2-\gamma)}{((n-1)\gamma + 2)(2-\gamma)} \quad (13)$$

with the total equilibrium consumption in a non-signatory  $l$ 's market from all varieties ( $Q_l^* = m q_{li}^* + (n-m) q_{lj}^*$ ) is given by:

$$Q_l^* = \frac{n(a-c) - m(t_i - t_j) - n t_j}{(n-1)\gamma + 2} \quad (14)$$

Next, we present the equilibrium quantities for all firms' varieties produced for a signatory's market ( $q_{ki}^*$  &  $q_{kj}^*$ ). We present the detailed quantities' derivation in Appendix 2.<sup>15</sup>

A signatory firm  $i$ 's variety produced for a signatory  $k$ 's market is given by:<sup>16</sup>

$$q_{ki}^* = \frac{(a-c)(2-\gamma) - \gamma(n-m)(t_i - t_j)(1-\phi) - t_i(2-\gamma)}{((n-1)\gamma + 2)(2-\gamma)} \quad (15)$$

and a non-signatory firm  $j$ 's variety produced for a signatory  $k$ 's market is given by:<sup>17</sup>

$$q_{kj}^* = \frac{(a-c)(2-\gamma) - (t_i - t_j)(\gamma(m(\phi-1) - \phi) + 2\phi) - t_j(2-\gamma)}{((n-1)\gamma + 2)(2-\gamma)} \quad (16)$$

with the total equilibrium consumption in a signatory  $k$ 's market from all varieties ( $Q_k^* = m q_{ki}^* + (n-m) q_{kj}^*$ ) is given by:<sup>18</sup>

$$Q_k^* = \frac{n(a-c) - (n-m)(t_i - t_j)(\phi-1) - n t_i}{(n-1)\gamma + 2} \quad (17)$$

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<sup>15</sup>Here we will illustrate the case whereby in the absence of the BTA policy in signatories' markets, the quantities  $q_{ki}^*$  and  $q_{kj}^*$ , will be of the same functional form as  $q_{li}^*$  and  $q_{lj}^*$  above, respectively. In other words,  $q_{ki}^*(.) = q_{li}^*(.)$  &  $q_{kj}^*(.) = q_{lj}^*(.)$ . Therefore, in the No BTA regime they boil down to  $q_{li}^*$  &  $q_{lj}^*$ , respectively, as the destination market does not matter anymore.

<sup>16</sup>Notice that one can drive the equilibrium quantity  $q_{ki}^*$  for the No BTA regime ( $t_i \leq t_j$ ) by setting  $\phi = 0$  in  $q_{ki}^*$ , in which case it becomes the same as  $q_{li}^*$  above.

<sup>17</sup>Similar to the previous footnote:  $q_{kj}^*$  in (16) under the No BTA regime ( $\phi = 0$ ) becomes the same as  $q_{lj}^*$ .

<sup>18</sup>Similar to the previous footnote:  $Q_k^*$  in (17) under the No BTA regime ( $\phi = 0$ ) becomes the same as  $Q_l^*$ .

Since the BTA policy is only valid when  $t_i > t_j$  and given our assumption of full adjustment:  $\phi = 1$ , we can draw the following intuitive conclusions, which can be verified from equations (12) to (20). First, consumers in a signatory  $k$ 's market consume the same amount from all varieties, be it produced by signatories' or non-signatories' firms:  $q_{ki}^* = q_{kj}^*$ ,  $\forall \gamma$ . This is due to the full adjustment ( $\phi = 1$ ), under which a non-signatory firm  $j$  de facto faces  $t_i$  when exporting its variety to a signatory  $k$ 's market. Second, given our assumption that  $t_i > t_j$ , this implies that total consumption in a signatory  $k$ 's market is lower than total consumption in a non-signatory  $l$ 's market:  $Q_k^* < Q_l^*$ ,  $\forall \gamma$ . Third, the total production of firm  $i$ 's variety is lower than total production of firm  $j$ 's variety:  $Q_i^* < Q_j^*$ ,  $\forall \gamma$ . Finally, the quantity of firm  $j$ 's variety produced for a non-signatory  $l$ 's market is higher than its quantity produced for a signatory  $k$ 's market:  $q_{lj}^* > q_{kj}^*$ ,  $\forall \gamma$ , given that  $t_i > t_j$ .

More formal conclusions are presented in Proposition 1 and Proposition 2 below.

### Proposition 1 - The Effects of Taxes on Equilibrium Quantities

*Suppose a coalition  $S$  has formed in the first stage and all players have chosen their equilibrium taxes in the second stage*

- *In the BTA regime, the quantities of firms  $i$ 's and  $j$ 's varieties in a signatory's market decrease in signatories' equilibrium taxes,  $\frac{\partial q_{ki}^*}{\partial t_i} < 0$  and  $\frac{\partial q_{kj}^*}{\partial t_i} < 0$ , while they remain unaffected by non-signatories' equilibrium taxes,  $\frac{\partial q_{kj}^*}{\partial t_j} = 0$  and  $\frac{\partial q_{ki}^*}{\partial t_j} = 0$ , irrespective of  $\gamma$ . The total quantity consumed in a signatory's market:  $\frac{\partial Q_k^*}{\partial t_i} < 0$  and  $\frac{\partial Q_k^*}{\partial t_j} = 0$ , irrespective of  $\gamma$ .*
- *In the BTA regime, the quantity of firm  $i$ 's ( $j$ 's) variety in a non-signatory's market decreases in signatories' (non-signatories') equilibrium taxes,  $\frac{\partial q_{li}^*}{\partial t_i} < 0$  ( $\frac{\partial q_{lj}^*}{\partial t_j} < 0$ ), and increases in non-signatories' (signatories') equilibrium taxes,  $\frac{\partial q_{li}^*}{\partial t_j} > 0$  ( $\frac{\partial q_{lj}^*}{\partial t_i} > 0$ ), except for  $\gamma = 0$  in which case  $\frac{\partial q_{li}^*}{\partial t_j} = 0$  ( $\frac{\partial q_{lj}^*}{\partial t_i} = 0$ ). The total quantity consumed in a non-signatory's market decreases in any equilibrium tax,  $\frac{\partial Q_l^*}{\partial t_i} < 0$  and  $\frac{\partial Q_l^*}{\partial t_j} < 0$ , irrespective of  $\gamma$ .*

**Proof:** Follows directly from equations (12) to (17) above. **Q.E.D.**

Under the BTA regime, quantities of any firm's variety (a signatory's or non-signatory's firm) produced for signatories' markets are negatively affected by signatories' taxes and not at all affected by non-signatories' taxes. This holds true irrespective of the TFV assumption, i.e.  $\gamma = [0, 1]$ . In signatories' markets, non-signatories' firms de facto face  $t_i^*$  under  $\phi = 1$  (i.e. equation (16) becomes  $q_{kj}^* = \frac{a-c-t_i}{(n-1)\gamma+2}$ , which is also the same for equation (15)  $q_{ki}^* = \frac{a-c-t_i}{(n-1)\gamma+2}$ ). In other words, non-signatories' taxes  $t_j$



have no strategic effects on any firm's production for signatories' markets due to the full BTA adjustment.

Quantities of any firm's variety (signatory's or non-signatory's firm) produced for non-signatories' markets under the BTA regime are negatively affected by own taxes and positively affected by foreign taxes. Only under full TFV, i.e.  $\gamma = 0$ , will a firm's output not be affected by a foreign tax imposed on a foreign firm. In which case, each firm acts as a monopolist in each market as consumers do not substitute between varieties and hence there is no competition among firms. Notice that these strategic interactions in non-signatories' markets under the BTA regime also apply under the No BTA regime not only for non-signatories' markets but also for signatories' ones as shown in Finus and Al Khourdajie (2017). This is true because there are no BTA adjustments in non-signatories' markets under the BTA regime, and of course no BTA adjustments in the No BTA regime.

Overall, these conclusions imply that using the BTA policy signatories' governments are more able to influence global emissions given that they control emission taxes in their own markets; an influential position they do not enjoy in the absence of the BTA policy.

## Proposition 2 - The Effects of BTAs on Production Patterns

*Suppose a coalition  $S$  has formed in the first stage and all players have chosen their equilibrium taxes in the second stage*

- *in a non-signatory's market, a non-signatory firm  $j$ 's output is always higher than a signatory firm  $i$ 's output,  $q_{lj}^* > q_{li}^*$ , irrespective of  $\gamma$ .*
- *a signatory firm  $i$ 's output for any signatory's market is higher than its output for any non-signatory's market,  $q_{ki}^* > q_{li}^*$ , except for  $\gamma = 0$  in which case  $q_{ki}^* = q_{li}^*$ .*

**Proof:** Follows directly from equations (12) to (17) above. **Q.E.D.**

Under the BTA regime, all varieties' levels produced for signatories' markets are the same,  $q_{ki}^* = q_{kj}^* = \frac{a-c-t_i}{n+1} \forall \gamma$ , where terms of trade are the same for all firms' (signatories' and non-signatories' ones) due to the full BTA adjustment. However, in non-signatories' markets we find that signatories firms' output  $q_{li}^* = \frac{a-c-(n-m)(t_i-t_j)-t_i}{n+1}$  is lower than non-signatories firms' one  $q_{lj}^* = \frac{a-c+m(t_i-t_j)-t_j}{n+1}$ ,  $q_{li}^* < q_{lj}^*$ .<sup>19</sup> Given that  $t_i > t_j$ , signatories' firms suffer from a comparative disadvantage  $-(n-m)(t_i-t_j)$  in  $q_{li}^*$  in non-signatories' market, while non-signatories' firms benefit from this tax differential  $(+m(t_i-t_j))$  in  $q_{lj}^*$ .

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<sup>19</sup>This is an example for  $\gamma = 1$ . However, the discussion applies for  $\gamma = [0, 1]$ .

From signatories' firms perspective, their production for signatories' markets  $q_{ki}^* = \frac{a-c-t_i}{n+1}$  must be higher than their production for non-signatories' markets  $q_{li}^* = \frac{a-c-(n-m)(t_i-t_j)-t_i}{n+1}$ , given the comparative disadvantage  $-(n-m)(t_i-t_j)$  they face in  $q_{li}^*$ . This holds true whenever varieties are substitutable,  $\gamma = (0, 1]$ . When varieties become independent such effect disappears, as we have shown in Proposition 1, (for  $\gamma = 0$ :  $q_{ki}^* = q_{li}^* = \frac{a-c-t_i}{n+1}$ ).

## 3.2 Second Stage

In this section, we derive equilibrium taxes for signatories and non-signatories in the second stage. The equilibrium taxes follow from the F.O.Cs. for signatories' and non-signatories' welfare functions. Check Appendix 3 below for the equilibrium taxes' equations. Furthermore, we find that the S.O.Cs. are satisfied.

Inserting equilibrium taxes into equilibrium quantities reveals that we need to impose non-negativity constraints in order to ensure positive outputs. Essentially, these constraints boil down to requesting that the demand parameter  $a$  is larger than marginal production cost  $c$  plus a multiple of marginal damages. In other words, this non-negativity constraint represents a lower threshold  $\underline{a}$ , such that  $a > \underline{a}$ . Furthermore, as mentioned earlier, in order for the BTA policy to be valid we need to ensure that the BTA constraint  $t_i^* > t_j^*$  is satisfied. This is achievable by identifying an upper threshold for the demand parameter such that  $a \leq \bar{a}$ . Above this threshold we find  $t_i^* \leq t_j^*$  as the coalition's joint welfare maximisation calls for lower taxes in order to maximise consumers' welfare.

We consider three values of TFV parameter: no TFV with  $\gamma = 1$ , partial TFV with  $\gamma = 0.5$ , and full TFV with  $\gamma = 0$ . Due to the complexity of the analytical results under the BTA regime we resort to full simulations in order to generate the constraints ( $\underline{a}$  &  $\bar{a}$ ) as well as all the subsequent results of the remainder of the paper. The parameters' constellations for the simulation are as follows:  $n = 10$ ,  $\gamma = \{0, 0.5, 1\}$ ,  $\delta = \{10, 50, 100\}$ ,  $c = 0$ ,<sup>20</sup> and full adjustment  $\phi = 1$ .

We present the details of driving both the non-negativity and BTA constraints for both regimes in Appendix 4, which results in having a parameters' space for each regime. Then we proceed in the analysis by creating a joint BTA and No BTA parameters' space such that both constraints are satisfied in both regime (i.e.  $\underline{a} < a \leq \bar{a}$ ) in order to be able to undertake comparative analysis. The joint parameters' space for both regimes is as follows:

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<sup>20</sup>Since we have constant marginal costs symmetric across all firms (signatories' and non-signatories' ones) such simplification,  $c = 0$ , will not affect our qualitative results.

	$\delta = 10$		$\delta = 50$		$\delta = 100$	
	$\underline{a}$	$\bar{a}$	$\underline{a}$	$\bar{a}$	$\underline{a}$	$\bar{a}$
$\gamma = 0$	101	104	501	520	1001	1040
$\gamma = 0.5$	120	1000	590	5300	1250	10500
$\gamma = 1$	250	5000	1350	25000	2500	50000

In order to cover the whole parameters' space, we break each range (for each  $\delta$  and  $\gamma$  combination) into 5 equidistant points using the interval  $\Delta = \frac{\bar{a}-\underline{a}}{5}$ . The value of  $a$  at each point would be given by  $a_i = a_{i-1} + \Delta$  for  $i = 1, \dots, 5$ . For instance:  $a_1 = \underline{a} + \Delta$  and  $a_5 = a_4 + \Delta \leq \bar{a}$ . Check Appendix 4 for further details.

In the results presented below we discuss the qualitative results that cover the whole parameters' space, i.e. all  $a$  values for the 5 equidistant points for each  $\delta$  and  $\gamma$  combination. We present the detailed results for each equidistant point in Appendix 6. We highlight the deviations in the results under particular values, if any, during the discussion.

## Result 1 - Comparing Equilibrium Taxes Across BTA and No BTA Regimes

*Whenever the BTA policy is introduced by the coalition (i.e. shifting to the BTA regime)*

- *signatories always increase their equilibrium emission taxes  $t_i^{BTA} > t_i^{NoBTA}$*
- *and non-signatories' increase their equilibrium emission taxes  $t_j^{BTA} > t_j^{NoBTA}$ , except for  $\gamma = 1$  they decrease their taxes when the coalition size is below certain threshold:  $t_j^{BTA} < t_j^{NoBTA}, \forall m \leq \tilde{m}$ , then they increase them above this threshold  $t_j^{BTA} > t_j^{NoBTA}, \forall m > \tilde{m}$ .*

The BTA policy provides signatory governments with an additional strategic tool to internalise externalities from emissions but also protecting their firms' competitiveness in the domestic markets. Furthermore, and importantly, it also serves as an additional source to collect taxes from imports produced but firms located in non-signatory countries. Therefore, taxes of signatory governments are higher under the BTA regime than under the No BTA regime.

From non-signatory government's point of view, BTA adjustments have the following implications. Firstly, their consumers need to pay higher prices for varieties supplied by firms located in signatory countries. Secondly, their firms face an additional tax burden at the borders to signatories' markets that will negatively affect their profits. Thirdly, they face a loss of potential tax revenue, i.e. tax revenue generated by their firms but which goes into signatory governments' coffers. Therefore, non-signatory governments reaction is complex. On the one hand, non-signatory governments could

raise their taxes in order to protect their tax revenues. On the other hand, they could lower their taxes to protect their consumers.

The incentive to protect domestic consumers decreases the lower the value of  $\gamma$  and vanishes for the full TFV with  $\gamma = 0$ . In our simulations, this incentive is also sufficiently low for  $\gamma = 0.5$ , such that for the full and partial TFV, i.e.  $\gamma = \{0, 0.5\}$  the tax protection effect dominates the consumer protection effect and hence non-signatory governments choose a higher tax under the BTA than under No BTA regime. For no TFV, i.e.  $\gamma = 1$ , this is also true if  $m > \tilde{m}$ , but is reversed if  $m \leq \tilde{m}$ . That is, the dominance of one driving force over the other depends on the size of the coalition they are exporting to. For small to medium coalition sizes non-signatories' governments reduce their emission taxes in order to protect their domestic consumers. Given that varieties are substitutable, having lower taxes imposed on the domestic firm helps consumers to substitute the expensive varieties imported from signatories' firms with the cheaper domestic one. For large coalition sizes, non-signatories' firms are faced with higher tax burden overall given the high number of signatories and hence there is a higher loss of potential revenue for the non-signatories' government. In such situation, non-signatories' governments choose higher taxes.

In all cases, the overall tax level under the BTA regime is higher than under the No BTA regime such that total output and hence total emissions are always lower for every coalition size (which does not include the grand coalition). Hence, we can already conjecture that provided equilibrium stable coalitions are larger under the BTA regime than under the No BTA regime, global emissions will be lower.

### 3.3 First Stage

#### Result 2 - Properties of the No BTA and BTA Coalition Games

*In the coalition game of the No BTA Regime, the properties of positive externality, full cohesiveness and hence cohesiveness hold strictly  $\forall \gamma$ . A signatory's welfare is always lower than a non-signatory's one  $\forall \gamma$ . Internal spillovers turn from negative into positive above certain coalition size threshold  $\tilde{m}$  (always positive,  $\forall m$ ) for  $\gamma = 1$  ( $\gamma = \{0, 0.5\}$ ). Superadditivity generally fails (always holds) for  $\gamma = 1$  ( $\gamma = \{0, 0.5\}$ ). More specifically:<sup>21</sup>*

$\gamma$	$W_i^{NoBTA} - W_j^{NoBTA}$	Externality	I Spillover	SAD	FC
1	—	+	— then +	—	+
0.5	—	+	+	+	+
0	—	+	+	+	+

<sup>21</sup>Legend: I Spillover: Internal Spillover. SAD: Superadditivity. FC: Full Cohesiveness. The input of “+”: implies holds or positive (depending on the property). The input of “—”: fails or negative.

*In the coalition game of the BTA Regime, the properties of superadditivity and cohesiveness hold strictly  $\forall \gamma$ . Full cohesiveness holds above certain coalition size threshold  $\tilde{m}$  (always holds,  $\forall m$ ) for  $\gamma = \{0.5, 1\}$  ( $\gamma = 0$ ). Externality is always negative (positive) for  $\gamma = 1$  ( $\gamma = 0$ ), while for  $\gamma = 0.5$  turns from negative into positive above certain coalition size threshold  $\tilde{m}$ . A signatory's welfare is always higher than a non-signatory's one, except for  $\gamma = 0$  there is a threshold of coalition size  $\tilde{m}$ , above which this inequality reverses. Internal spillovers turn from positive into negative above certain coalition size threshold  $\tilde{m}$  (always positive,  $\forall m$ ) for  $\gamma = \{0.5, 1\}$  ( $\gamma = 0$ ). More specifically:*

$\gamma$	$W_i^{BTA} - W_j^{BTA}$	Externality	I Spillover	SAD	FC
1	+	−	+ then −	+	− then +
0.5	+	− then +	+ then −	+	− then +
0	+ then −	+	+	+	+

*When signatories shift to the BTA regime, each individual signatory's welfare always increases  $\forall \gamma$ , and each individual non-signatory's welfare decreases for  $\gamma = \{0.5, 1\}$ , while for  $\gamma = 0$  there is a coalition size threshold  $\tilde{m}$ , above which their individual welfare increases. More specifically:*

$\gamma$	$W_i^{BTA} - W_i^{NoBTA}$	$W_j^{BTA} - W_j^{NoBTA}$
1	+	−
0.5	+	−
0	+	+ then −

Findings in Result 2 for the No BTA regime show that the normative property of full cohesiveness holds with the highest level of global welfare achieved under the grand coalition. That is, the global welfare is increasing in the coalition size due to the increasing internalisation of the damage externality. Findings also illustrate the incentives of free riding on the coalition's efforts, as the externality property is always positive. The incentives to join the coalition, represented by the property of superadditivity, exist only for  $\gamma = \{0, 0.5\}$ . For  $\gamma = 1$  superadditivity holds only for the move from a coalition with  $m^* = n - 1$  signatories to the grand coalition  $m^* = n$ . Due to full substitutability of varieties ( $\gamma = 1$ ), the emission reduction efforts of signatories are fully undermined by the reaction of non-signatories. However, when varieties are not fully substitutable,  $\gamma = \{0, 0.5\}$ , then such leakage effects are undermined and hence superadditivity holds in these cases. Finally, signatories are always worse-off than non-signatories for each possible coalition size and for all  $\forall \gamma$  as their firms and consumers are incurring the costs of emission reductions.

Looking at the internal spillovers resulting from enlarging the coalition under the No BTA regime, we find that for  $\gamma = \{0, 0.5\}$  they are always positive. However, for  $\gamma = 1$  they are negative for small to medium coalition sizes ( $-, \forall m^* = [2, 5], \forall a$  where  $\underline{a} <$

$a \leq \bar{a}$ ), then they turn into positive. Again, this relates to the fact that when varieties are perfect substitutes under  $\gamma = 1$  the leakage effects undermine the coalition's emission reductions efforts. Such effects are less pronounced for large coalitions, and hence the internal spillovers become positive. Furthermore, signatories' firms face strong comparative disadvantage due to the emission tax when varieties are perfect substitutes, as shown in Proposition 2. Whenever varieties matter ( $\gamma = \{0, 0.5\}$ ), the internal spillovers are always positive due to low leakage effects.

When signatories shift to the BTA regime, we find the incentives to join the coalition are strong as superadditivity hold in all cases,  $\forall \gamma$ . The more countries join the coalition, the higher are emission reductions efforts. Furthermore, new signatories can also generate additional tax revenue from the BTA policy. These benefits outweigh the loss of less BTA tax revenue that existing signatories face when a new country joins the coalition. Forming and enlarging a coalition under the BTA regime has two effects on non-signatories. First, the effects of the additional taxes that non-signatories' firms face when they export to signatories' markets. These effects are always negative irrespective of TFV. Second, the effects of the coalition's emission reduction efforts, which in principle are always positive. However, the degree of these positive spillovers depend on the TFV. Under  $\gamma = 1$ , these positive spillovers are undermined by non-signatories' reactions due to the full substitutability of varieties. Hence, in such case the net externalities are negative. Under  $\gamma = 0.5$ , these positive spillovers are not fully undermined by non-signatories' reactions, and hence they matter turning the externality into positive for large coalitions. Under  $\gamma = 0$ , these positive spillovers can not be undermined by non-signatories' reactions and hence the externality is always positive.

When a new country joins the coalition, this has two effects on the individual welfare of existing signatories. First, they benefit from the higher emission reductions by the new signatory. These benefits matter more when TFV is high. Second, they generate less BTAs revenues, which always has negative effects irrespective of the TFV. Therefore, for  $\gamma = \{0.5, 1\}$ , the internal spillovers of enlarging the BTA coalition are positive for small to medium coalition sizes then they turn into negative due to lower border tax revenue generated given the very small number of non-signatories. For  $\gamma = 0$ , the emission reduction efforts always count and hence the internal spillovers are always positive. Overall, signatories' welfare is always larger than non-signatories' one given the BTA revenues, except when  $\gamma = 0$  where non-signatories' welfare is larger than signatories' one for large coalition sizes as they benefit more from the coalition's emission reduction efforts.

Looking at the full cohesiveness property for  $\gamma = \{0.5, 1\}$ , global welfare decreases for small to medium coalition sizes as the negative externalities toward non-signatories are very strong and outweigh the BTA tax revenue benefits that signatories are enjoying. Full cohesiveness turns into positive for large coalitions as more countries globally are enjoying the BTA tax revenues benefits. For full TFV, i.e.  $\gamma = 0$ , full cohesiveness always holds given that superadditivity holds and externalities are

positive.

All in all, the effects of shifting toward the BTA regime can be summarised in two folds. First, BTAs turn the externality property into negative in most cases for  $\gamma = \{0.5, 1\}$  and hence undermining the incentives for free riding. Second, BTAs ensure that superadditivity holds in all cases  $\forall \gamma$ . Therefore, the BTA policy provide high incentives for cooperation and result in large coalitions to be stable in equilibrium, as we will show in Result 3 and 4 below.

Comparing the welfare effects on individual countries after the coalition shifts to the BTA regime, we find that signatories always become better off given the additional tax revenue they generate as well as the lower damages. As for non-signatories, we find that for  $\gamma = \{0.5, 1\}$  they become worse-off given the negative externalities. However, when TFV is at the highest level, i.e.  $\gamma = 0$ , non-signatories become better off when small coalitions shift to the BTA regime as they benefit from the higher emission reduction activities. Only when the BTA coalition is large, non-signatories become worse off given the higher number of markets in which their firms face BTAs.

### Result 3 - Coalitions under Internal and External Stability

*Let  $m^*$  denotes the size of an internally and externally stable coalition. Introducing the BTA policy leads to the grand coalition,  $m^* = n$ , to be stable in equilibrium under partial and no TFV,  $\gamma = \{0.5, 1\}$  respectively. Under full TFV,  $\gamma = 0$ , large, but not grand, coalitions become stable in equilibrium. More specifically:*

$\gamma$	No BTA $\rightarrow$ BTA Regime
1	$m^{*NoBTA} = 1 \rightarrow m^{*BTA} = n$
0.5	$m^{*NoBTA} = 2 \rightarrow m^{*BTA} = n$
0	$m^{*NoBTA} = 3 \rightarrow m^{*BTA} < n$

We find that shifting to the BTA regime yields the grand coalition to be always stable in equilibrium for  $\gamma = \{0.5, 1\}$ . This is true for the whole parameters' space. For  $\gamma = 0$  large coalitions are stable in equilibrium,  $m^* = \{8, 9\}$ , where the exact size depends on the parameter  $a$  values (i.e. between  $\bar{a}$  and  $\underline{a}$ ).<sup>22</sup> One can look at these results from another angle: the effects of TFV reverses when comparing the No BTA versus BTA regimes. Under the No BTA regime higher TFV renders larger coalitions to be stable. Under the BTA regime higher TFV leads to less cooperation.

As we showed in Result 2 above, the incentives for free riding on the coalition's emission reduction efforts under the No BTA regime always exist as the externality property is always positive. The incentives to join the coalition are represented by the property of superadditivity. We find that these incentives depend on the level

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<sup>22</sup>Check Appendix 6 for more detailed results for each value of  $a$ .

of consumers' taste for variety. Starting with  $\gamma = 1$ , due to the full substitutability of varieties the emission reduction efforts of signatories are fully undermined by the reaction of non-signatories. Therefore, superadditivity fails and we find no stable coalition in equilibrium. However, when varieties are not fully substitutable,  $\gamma = \{0, 0.5\}$ , then such leakage effects are lower and hence superadditivity holds in these cases, providing stronger incentives for cooperation. Nevertheless, the positive externalities are strong enough to outweigh the benefit from cooperation and hence we find for  $\gamma = 0.5$  a stable coalition of  $m^* = 2$  and for  $\gamma = 0$  a stable coalition of  $m^* = 3$ . It is evident that when varieties are completely independent ( $\gamma = 0$ ) the leakage effects are at the minimal and hence the largest No BTA coalition of  $m^* = 3$ , comparing to other levels of TFV, forms.

Introducing the BTA policy provides stronger incentives to join the coalition due to the benefits of the BTAs revenues for signatories. Furthermore, signatories are also able to enforce stronger emission reductions in their own markets as their taxes also apply to non-signatories' imports. From non-signatories' perspective, under the BTA regime the incentives for free riding are undermined, in most cases, due to the negative effects of BTAs on their firms. Therefore, under the BTA regime we find larger stable coalitions comparing to the No BTA regime for any given level of TFV. In the case of partial and no TFV,  $\gamma = \{0.5, 1\}$  respectively, the BTA policy mitigates any free riding incentives through the posed negative externalities toward non-signatories and hence the grand coalition becomes stable in equilibrium, comparing to small or no coalitions under No BTA regime. However, for high TFV,  $\gamma = 0$ , non-signatories enjoy positive rather than negative externalities. The reason for this is that when varieties are not substitutable, signatories impose higher taxes as they will not face a large negative response (leakage effects) from non-signatories. This in turn leads to positive externalities given the higher emission reductions. Nevertheless, the incentives for forming coalitions are high enough to yield large coalitions to be stable in equilibrium.

In the next result we look for a coalition size that achieves the highest individual welfare of all signatories. We consider that if exclusive membership rule is allowed, then it is in the interest of countries to search for and form such coalition, and not allow additional countries to join it. The coalition formation process is based on our internal spillover property.

#### **Result 4 - Coalitions under Exclusive Membership**

*Let  $m^*$  denotes the size of a BTA stable coalition under exclusive membership. The size of stable coalitions under partial and no TFV,  $\gamma = \{0.5, 1\}$  respectively, is given by  $m^* = [5, 8]$ .*

Under the BTA regime, higher signatory's individual welfare can be achieved under smaller coalitions' sizes than the grand coalition. The deriving force behind this is given by the internal spillovers property: when a new country joins the coalition



the individual welfare of existing signatories would increase up to a certain coalition size threshold, after which the individual welfare of existing signatories starts to decrease. This is true because signatories' individual welfare is maximised when there are few countries outside the coalition from whom they can generate BTA revenues. The negative effects on consumers are minimal as varieties are fully/partially substitutable.

More specifically, the size of such coalition under  $\gamma = 1$  is given by  $m^* = \{5, 6\}$ , and under  $\gamma = 0.5$  is given by  $m^* = [5, 8]$ . The exact size depends on the parameter  $a$  values (i.e. between  $\bar{a}$  and  $\underline{a}$ ).<sup>23</sup> Generally, the size of the stable coalition is decreasing with the parameter  $a$  values, i.e. it is decreasing as demand increases. This is intuitive given that allowing additional country to join the coalition would generate higher losses of missing on potential BTA revenues given the very high demand.<sup>24</sup>

## 4 Concluding Remarks

In an intra-industry trade model with horizontal products' differentiation and consumers' taste for variety (TFV) we studied the formation and stability of international climate change agreements under free trade. We extended Finus and Al Khourdajie (2017) paper by providing the climate change agreement's signatories with an additional policy instrument called border tax adjustment (BTA). Using this policy signatory governments can impose an additional border tax on imports from non-signatories' firms. This border tax amounts to the tax differential between the high emission taxes that signatory firms are facing in their domestic markets and the low emission taxes that non-signatory firms are facing for their exports to these markets.

In generating our results we focused on three cases of TFV. Firstly, "no TFV" under which varieties are perfect substitutes. Secondly, "partial TFV" that implies some degree of substitutability among varieties. Thirdly, "full TFV" under which consumers have high preference for a balanced consumption bundle and varieties are independent. Stability of the coalition leading to an agreement was tested using the internally and externally stability concept. We also introduced an extension of this concept to allow for exclusive membership rule. In this setup we examined the effects of border tax adjustments in influencing countries' decisions on their emission taxes as well as membership status by comparing two cases: climate agreements with and without border tax adjustments, BTA and No BTA regimes, respectively.

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<sup>23</sup>Check Appendix 6 for more detailed results for each value of  $a$ .

<sup>24</sup>As for  $\gamma = 0$ , the internal spillovers are always positive under the BTA regime for all coalition sizes as we showed in Result 2 above. In other words,  $m^* = n$  is the coalition that achieves the highest individual signatory's welfare under  $\gamma = 0$ . We do not consider this result here as it is difficult to justify against an internally and externally stable coalition of  $m^* = 7$ .

Relating the TFV feature to the intuition of loss of competitiveness, one has to note the following. Under no (or partial) TFV, there exists (some) loss of competitiveness facing firms in signatory countries. This effect however disappears under high TFV as varieties are independent and firms de facto act as monopolists over their unique variety. Therefore, when varieties are not (or somewhat) important, BTAs play an important role in tackling loss of competitiveness and hence free riding. However, when varieties do matter to consumers, BTAs become merely a policy tool for additional tax revenue generation for signatories. Nevertheless, they do tackle free riding given the additional costs on non-signatories firms' exports.

Similarly, relating the TFV feature to the intuition of emission leakage, under no (or partial) TFV, given the full (partial) substitutability of varieties non-signatories can fully (partially) undermine signatories' emission reduction efforts leading to emission leakage. However, under full TFV, varieties are independent and hence there are no leakage effects.

We found that introducing BTAs under no or partial TFV enhances the incentives to join the coalition as signatories generate additional tax revenues given the BTA policy. Furthermore, BTAs undermine the free riding incentives as the coalition exhibits negative externalities toward non-signatories. Under internal and external stability, these driving forces together led to the grand coalition to be stable in equilibrium. When the exclusive membership rule is considered, we found only medium-sized coalitions are stable in equilibrium, as signatories of these coalitions are enjoying the additional tax revenues they are generating through the BTAs and hence they do not allow all countries to join the coalition.

Looking at the full TFV case, introducing BTAs doesn't lead to negative externalities against non-signatories anymore. Since varieties are independent, signatories' emission reduction efforts can not be undermined by non-signatories' reactions. Therefore, signatories impose higher taxes as they will not face a large negative response (leakage effects) from non-signatories. As a result, each non-signatory benefits from signatories' efforts. These benefits outweigh the negative effects of the BTAs, leading to positive externalities. Nevertheless, given the additional BTA revenue that signatories enjoy, countries always have the incentives to join the coalition and hence large coalitions are stable in equilibrium under internal and external stability.

To our knowledge this is the first attempt to introduce the combination of border tax adjustment, horizontal products' differentiation and consumers' TFV features to the literature of self-enforcing IEAs under free trade. Future research avenues could be explored in terms of relaxing the symmetry assumption, and understanding the effect of ideal varieties or asymmetric consumers' TFV between countries. Furthermore, one can introduce an additional policy instrument for non-signatories such as tax rebates that allow them to mitigate the BTAs negative effects on their firms' profit when they export to signatories' markets.

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## 6 Appendixes

A detailed appendix with the full details of all derivations is available upon request. Below, we summarise the most important steps in the derivation in a compact form.

### 6.1 Appendix 1: Properties of the Game

For all  $S \subset N$ ,  $S \neq \emptyset$ , and  $S' = S \cup \{j\}$  where  $S' \subseteq N$ :

- **Positive Internal Spillover:** in a coalition game a move from coalition  $S$  to coalition  $S'$  exhibits (strict) positive internal spillovers if:

$$W_i(S') \geq (>) W_i(S) \quad \forall i \in S \text{ and } i \in S'$$

- **Negative Internal Spillover:** in a coalition game a move from coalition  $S$  to coalition  $S'$  exhibits strict negative internal spillovers if:

$$W_i(S') < W_i(S) \quad \forall i \in S \text{ and } i \in S'$$

- **Superadditivity:** in a coalition game a move from coalition  $S$  to coalition  $S'$  is (strictly) superadditive if:

$$\sum_{i \in S'} W_i(S') \geq (>) \sum_{i \in S} W_i(S) + W_j(S) \quad \forall j \notin S$$

We characterise the relationship between the internal spillover (positive and negative) and superadditivity properties as follows.

There are two main cases. The first case is where the non-signatory remains at least as well off after joining the coalition as being a singleton, i.e.  $W_j(S \cup \{j\}) - W_j(S) \geq 0$ . In which case if the positive internal spillover (PIS) property holds then superadditivity (SAD) must hold. That is, if PIS holds  $W_i(S \cup \{j\}) - W_i(S) \geq 0$ , knowing that the new signatory is at least as well off as before joining the coalition  $W_j(S \cup \{j\}) - W_j(S) \geq 0$ , then it must be the case that SAD also holds (weakly or strictly), i.e.  $(\sum_{i \in S} W_i(S \cup \{j\}) + W_j(S \cup \{j\})) - (\sum_{i \in S} W_i(S) + W_j(S)) \geq 0$ . If the negative internal spillover (NIS) property holds  $W_i(S \cup \{j\}) - W_i(S) < 0$  (i.e. PIS doesn't hold) then there are two scenarios to determine whether or not superadditivity (SAD) holds. The first scenario is where the joint loss of the current signatories (given by  $\sum_{i \in S} W_i(S \cup \{j\}) - \sum_{i \in S} W_i(S) < 0$ ) is at most equals to the individual benefit of the new signatory (i.e. the non-signatory who just joined, given by  $W_j(S \cup \{j\}) - W_j(S) > 0$ ), then in this case SAD holds strictly or weakly. That is,  $|\sum_{i \in S} W_i(S \cup \{j\}) - \sum_{i \in S} W_i(S)| \leq |W_j(S \cup \{j\}) - W_j(S)|$ , then SAD holds (strictly or weakly). The second scenario is where the joint loss of the current signatories is greater than the individual benefit of the new signatory, then in this case SAD fails. That is,  $|\sum_{i \in S} W_i(S \cup \{j\}) - \sum_{i \in S} W_i(S)| > |W_j(S \cup \{j\}) - W_j(S)|$ .

The second case is when the non-signatory becomes worse off after joining the coalition than being a singleton, i.e.  $W_j(S \cup \{j\}) - W_j(S) < 0$ . In which case if the negative internal spillover (NIS) property holds, then superadditivity (SAD) must fail. That is, if NIS holds  $W_i(S \cup \{j\}) - W_i(S) < 0$ , knowing that the new signatory is worse off after joining the coalition  $W_j(S \cup \{j\}) - W_j(S) < 0$ , then it must be the case that SAD fails, i.e.  $(\sum_{i \in S} W_i(S \cup \{j\}) + W_j(S \cup \{j\})) - (\sum_{i \in S} W_i(S) + W_j(S)) < 0$ . If the positive internal spillover (PIS) property holds strictly  $W_i(S \cup \{j\}) - W_i(S) > 0$  (i.e. NIS doesn't hold) then there are two scenarios to determine whether or not superadditivity (SAD) holds. The first scenario is where the joint benefit of the current signatories (given by  $\sum_{i \in S} W_i(S \cup \{j\}) - \sum_{i \in S} W_i(S) > 0$ ) is at least equal to the individual loss of the new signatory (i.e. the non-signatory who just joined, given by  $W_j(S \cup \{j\}) - W_j(S) < 0$ ), then in this case SAD holds (strictly or weakly). That is,

$|\sum_{i \in S} W_i(S \cup \{j\}) - \sum_{i \in S} W_i(S)| \geq |W_j(S \cup \{j\}) - W_j(S)|$ , then SAD holds (strictly or weakly). The second scenario is where the joint benefit of the current signatories is less than the individual loss of the new signatory, then in this case SAD fails. That is,  $|\sum_{i \in S} W_i(S \cup \{j\}) - \sum_{i \in S} W_i(S)| < |W_j(S \cup \{j\}) - W_j(S)|$ .

## 6.2 Appendix 2: Equilibrium Quantities Derivations

### 6.2.1 BTA Regime

The segmented market structure under the BTA regime is given by:

BTA Regime	Signatory firm $i$	Non-signatory firm $j$	Total Consumption
Signatory market $k$	$q_{ki}^*$	$q_{kj}^*$	$Q_{k.}^*$
Non-signatory market $l$	$q_{li}^*$	$q_{lj}^*$	$Q_{l.}^*$
Total Production	$Q_{.i}^*$	$Q_{.j}^*$	$Q$

#### Non-signatories' Markets:

We use the replacement functions method in order to derive the equilibrium quantities produced for a non-signatory's market  $q_{li}^*$  &  $q_{lj}^*$ .

The profit of firm  $i$  in market  $l$  is given by  $\pi_{li} = q_{li}(p_{li} - c - t_i)$ . Substituting the inverse demand function from equation (4) above after the appropriate changes in notation, we derive the following first order condition:

$$\frac{\partial \pi_{li}}{\partial q_{li}} = a - c - t_i - (2 - \gamma)q_{li} - \gamma Q_{l.} = 0 \iff a - c - t_i - 2q_{li} - \gamma \sum_{h \in N, h \neq i} q_{lh} = 0 \quad (18)$$

where  $Q_{l.}$  is the total quantity consumed in market  $l$  and  $\sum_{h \in N, h \neq i} q_{lh}$  is the sum of all consumed varieties by consumers in market  $l$  from all firms except firm  $i$ . Equation (21) shows that the reaction functions ( $q_{li} = r_i(\sum_{h \in N, h \neq i} q_{lh})$ ) have a slope of  $-\gamma/2$ . Hence, the equilibrium is unique; the absolute value of the slope of the reaction function increases with the taste of variety parameter  $\gamma$ , and as  $\gamma$  approaches zero the strategic interaction among firms vanishes. Moreover, a necessary condition for positive quantities is  $a > c$ . Below, we will further develop this non-negativity conditions in order to ensure interior solutions.

The profit of firm  $j$  in market  $l$  is given by  $\pi_{lj} = q_{lj}(p_{lj} - c - t_j)$ . Substituting the inverse demand function from equation (4) above after the appropriate changes in notation, we derive the following first order condition:

$$\frac{\partial \pi_{lj}}{\partial q_{lj}} = a - c - t_j - (2 - \gamma)q_{lj} - \gamma Q_l = 0 \iff a - c - t_j - 2q_{lj} - \gamma \sum_{h \in N, h \neq j} q_{lh} = 0 \quad (19)$$

In order to derive the equilibrium quantities, we note that, as mentioned in the game setup above, in stage 2 the equilibrium taxes are symmetric with all signatories choosing the same tax rate  $t_i$  and all non-signatories choose the same tax rate  $t_j$ , given symmetry. Furthermore, given our segmented market structure quantities produced for non-signatories' markets are the same; signatories' firms produce the same output for all non-signatories' markets, and non-signatories' firms produce the same output for their domestic market as well as all other non-signatories' markets.

Summing up the first order conditions in (18) and (19) above after multiplying them by the number of signatories  $m$  and the number of non-signatories  $n - m$  respectively, we find  $Q_l^*$  is given by:

$$Q_l^* = \frac{n(a - c) - m(t_i - t_j) - nt_j}{(n - 1)\gamma + 2} \quad (20)$$

Next we plug  $Q_l^*$  from (20) into (18) and solve for  $q_{li}^*$ , which is the signatory firm  $i$ 's output for a non-signatory  $l$ 's market:

$$q_{li}^* = \frac{(a - c)(2 - \gamma) - \gamma(n - m)(t_i - t_j) - t_i(2 - \gamma)}{((n - 1)\gamma + 2)(2 - \gamma)} \quad (21)$$

Similarly, we plug  $Q_l^*$  from (20) into (19) and solve for  $q_{lj}^*$ , which is the non-signatory firm  $j$ 's output for a non-signatory  $l$ 's market:

$$q_{lj}^* = \frac{(a - c)(2 - \gamma) + \gamma m(t_i - t_j) - t_j(2 - \gamma)}{((n - 1)\gamma + 2)(2 - \gamma)} \quad (22)$$

### Signatories' Markets:

We also use the replacement functions method in order to derive the equilibrium quantities produced for a signatory's market  $q_{ki}^*$  &  $q_{kj}^*$ .

The profit of firm  $i$  in market  $k$  is given by  $\pi_{ki} = q_{ki}(p_{ki} - c - t_i)$ . Substituting the inverse demand function from equation (4) above after the appropriate change in notation, we derive the following first order condition:

$$\frac{\partial \pi_{ki}}{\partial q_{ki}} = a - c - t_i - (2 - \gamma)q_{ki} - \gamma Q_k = 0 \iff a - c - t_i - 2q_{ki} - \gamma \sum_{h \in N, h \neq i} q_{kh} = 0 \quad (23)$$



The profit of firm  $j$  in market  $k$  is given by  $\pi_{kj} = q_{kj}(p_{kj} - c - t_j - \phi(t_i - t_j))$ . Notice that we are deriving the first order condition in the case where the BTA policy ( $t_i > t_j$ ) is valid and hence  $\Omega = \phi(t_i - t_j)$ . Check equation (10) above for further details. Substituting the inverse demand function from equation (4) above after the appropriate change in notation, we derive the following first order condition:

$$\frac{\partial \pi_{kj}}{\partial q_{kj}} = a - c - t_j - \phi(t_i - t_j) - (2 - \gamma)q_{kj} - \gamma Q_{k.} = 0 \iff a - c - t_j - \phi(t_i - t_j) - 2q_{kj} - \gamma \sum_{h \in N, h \neq j} q_{kh} = 0 \quad (24)$$

Summing up the first order conditions in (23) and (24) above after multiplying them by the number of signatories  $m$  and the number of non-signatories  $n - m$  respectively, we find  $Q_{k.}^*$  is given by:

$$Q_{k.}^* = \frac{n(a - c) - (n - m)(t_i - t_j)(\phi - 1) - nt_i}{(n - 1)\gamma + 2} \quad (25)$$

Next we plug  $Q_{k.}^*$  from (25) into (23) and solve for  $q_{ki}^*$ , which is signatory firm  $i$ 's output to a signatory  $k$ 's market:

$$q_{ki}^* = \frac{(a - c)(2 - \gamma) - \gamma(n - m)(t_i - t_j)(1 - \phi) - t_i(2 - \gamma)}{((n - 1)\gamma + 2)(2 - \gamma)} \quad (26)$$

Similarly, we plug  $Q_{k.}^*$  from (25) into (24) and solve for  $q_{kj}^*$ , which is non-signatory firm  $j$ 's output to a signatory  $k$ 's market:

$$q_{kj}^* = \frac{(a - c)(2 - \gamma) - (t_i - t_j)(\gamma(m(\phi - 1) - \phi) + 2\phi) - t_j(2 - \gamma)}{((n - 1)\gamma + 2)(2 - \gamma)} \quad (27)$$

### 6.2.2 No BTA Regime

We now look at markets under the No-BTA regime. Given our assumption of segmented market structure each firm supplies its good to the domestic and all foreign markets. Since the tax imposed on production is not differentiated based on the destination market and there are no BTA adjustments in the No BTA regime, the equilibrium quantity of any firm's variety is the same for all markets. That is, because of the segmentation of markets firms play a separate and identical Cournot game in each market. Therefore, there are two equilibrium quantities in the No BTA regime irrespective of the destination market. The first  $q_i^*$  represents signatory firm  $i$ 's production to any market.<sup>25</sup> The second equilibrium quantity  $q_j^*$  represents non-

<sup>25</sup>Notation: we replace the first subscript with a dot in order to illustrate the idea that a signatory's firm produces the same output irrespective of the destination market. Same applies for a non-signatory's firm, as we will show next.

signatory firm  $j$ 's production to any market. The segmented market structure under the No BTA regime can be illustrated in the following table:

No BTA Regime	Signatory firm $i$	Non-signatory firm $j$	Total Consumption
Signatory market $k$	$q_i^*$	$q_j^*$	$mq_i^* + (n - m)q_j^*$
Non-signatory market $l$			
Total Production	$nq_i^*$	$nq_j^*$	$n(mq_i^* + (n - m)q_j^*)$

We use the replacement functions method in order to derive the equilibrium quantities produced for a non-signatory's market  $q_i^*$  &  $q_j^*$ .

The profit of firm  $i$  in any market is given by  $\pi_i = q_i(p_i - c - t_i)$ . Substituting the inverse demand function from equation (4) above after the appropriate changes in notation, we derive the following first order condition:

$$\frac{\partial \pi_i}{\partial q_i} = a - c - t_i - (2 - \gamma)q_i - \gamma Q = 0 \iff a - c - t_i - 2q_i - \gamma \sum_{h \in N, h \neq i} q_h = 0 \quad (28)$$

where  $Q$  is the total quantity consumed in any market and  $\sum_{h \in N, h \neq i} q_h$  is the sum of all consumed varieties from all firms except firm  $i$ .

The profit of firm  $j$  in any market is given by  $\pi_j = q_j(p_j - c - t_j)$ . Substituting the inverse demand function from equation (4) above after the appropriate changes in notation, we derive the following first order condition:

$$\frac{\partial \pi_j}{\partial q_j} = a - c - t_j - (2 - \gamma)q_j - \gamma Q = 0 \iff a - c - t_j - 2q_j - \gamma \sum_{h \in N, h \neq j} q_h = 0 \quad (29)$$

Summing up the first order conditions in (28) and (29) above after multiplying them by the number of signatories  $m$  and the number of non-signatories  $n - m$  respectively, we find  $Q^*$  is given by:

$$Q^* = \frac{n(a - c) - m(t_i - t_j) - nt_j}{(n - 1)\gamma + 2} \quad (30)$$

Next we plug  $Q^*$  from (30) into (28) and solve for  $q_i^*$ , which is the signatory firm  $i$ 's output for any market:

$$q_i^* = \frac{(a - c)(2 - \gamma) - \gamma(n - m)(t_i - t_j) - t_i(2 - \gamma)}{((n - 1)\gamma + 2)(2 - \gamma)} \quad (31)$$

Similarly, we plug  $Q^*$  from (30) into (29) and solve for  $q_j^*$ , which is the non-signatory firm  $j$ 's output for any market:

$$q_j^* = \frac{(a-c)(2-\gamma) + \gamma m(t_i - t_j) - t_j(2-\gamma)}{((n-1)\gamma + 2)(2-\gamma)} \quad (32)$$

## 6.3 Appendix 3: Equilibrium Taxes

### 6.3.1 No BTA Regime Equilibrium Taxes

We derive the F.O.C.s for signatories and non-signatories in stage 2 of the game. Solving these conditions simultaneously, we find the equilibrium taxes for signatories and non-signatories as follows:

- For  $\gamma = 1$ :

$$t_i^* = \frac{n\delta(m(2-m) + n(n(m-1) + m(3-m) - 1)) - (a-c)(m(n^2 + (1-m)(n+1)))}{mn(n^2 + (1-m)(n+1))}$$

$$t_j^* = -\frac{n\delta(m-2)(n+1) + (a-c)(n^2 + (1-m)(n+1))}{n(n^2 + (1-m)(n+1))}$$

- For  $\gamma = 0.5$ :

$$t_i^* = \frac{(a-c)(n(-2n^3 - 10n^2 + n(2m^2 - 8m - 9) + 6m^2 - 27m + 9) + 9m)}{n(2n^4 + 14n^3 - n^2(2m^2 + m - 32) - n(7m^2 + 5m - 18) - 3m^2 - 9m - 18) + 9m}$$

$$+ \frac{n\delta(n^3(9m-3) - n^2(3m^2 - 48m + 9) - n(9m^2 - 54m) - 27m)}{n(2n^4 + 14n^3 - n^2(2m^2 + m - 32) - n(7m^2 + 5m - 18) - 3m^2 - 9m - 18) + 9m}$$

$$t_j^* = \frac{(a-c)(n(-2n^3 - 10n^2 + n(2m^2 + m - 18) + 6m^2 - 18) + 9m)}{n(2n^4 + 14n^3 - n^2(2m^2 + m - 32) - n(7m^2 + 5m - 18) - 3m^2 - 9m - 18) + 9m}$$

$$+ \frac{n\delta(6n^3 - n^2(3m^2 - 3m - 36) - n(9m^2 - 54) - 27m)}{n(2n^4 + 14n^3 - n^2(2m^2 + m - 32) - n(7m^2 + 5m - 18) - 3m^2 - 9m - 18) + 9m}$$

- For  $\gamma = 0$ :

$$t_i^* = \frac{(2n\delta - a + c)m}{2n - m}$$

$$t_j^* = \frac{2n\delta - a + c}{2n - 1}$$

### 6.3.2 BTA Regime Equilibrium Taxes

Due to the size of these equations, they are provided in PDF format with the CD attached to the thesis.

## 6.4 Appendix 4: Parameters Constellations

Inserting equilibrium taxes into equilibrium quantities reveals that we need to impose non-negativity constraints in order to ensure positive outputs. Essentially, these constraints boil down to requesting that the demand parameter  $a$  is larger than marginal production cost  $c$  plus a multiple of marginal damages. In other words, this non-negativity constraint represents a lower threshold  $\underline{a}$ , such that  $a > \underline{a}$ . Furthermore, as mentioned earlier, in order for the BTA policy to be valid we need to ensure that the BTA constraint  $t_i^* > t_j^*$  is satisfied. This is achievable by identifying an upper threshold for the demand parameter such that  $a \leq \bar{a}$ . Above this threshold we find  $t_i^* \leq t_j^*$  as the coalition's joint welfare maximisation calls for lower taxes in order to maximise consumers' welfare.<sup>26</sup>

### 6.4.1 Non-negativity Constraints

We first start with the No BTA regime. Finus and Al Khourdajie (2017) present the analytical non-negativity constraints for the No BTA regime for  $\gamma = \{0, 1\}$ . In Appendix 5 of this paper we present these non-negativity constraints again and introduce the non-negativity constraint for  $\gamma = 0.5$ . There are two equilibrium quantities in the No BTA regime:  $q_i^*$  for signatories and  $q_j^*$  for non-signatories. Each of them has a non-negativity constraint and we look for the most restrictive constraint  $\underline{a}$  such that  $q_i^* > 0$  and  $q_j^* > 0$  are satisfied.

In the case of the BTA regime, we also establish the non-negativity constraints for  $\gamma = \{0, 0.5, 1\}$ . There are four equilibrium quantities in the BTA regime:  $q_{ii}^*$ ,  $q_{ij}^*$ ,  $q_{ji}^*$ , and  $q_{jj}^*$  as presented above. Each of these quantities have a non-negativity constraint and we look for the most restrictive constraint  $\underline{a}$ , such that  $q_{ii}^* > 0$ ,  $q_{ij}^* > 0$ ,  $q_{ji}^* > 0$ , and  $q_{jj}^* > 0$  are satisfied. Due to the complexity of the constraints we resort to numerical simulations, and therefore we also present the corresponding constraints for the No BTA regime in numerical values too so that we undertake comparative analysis for both regimes. All values are presented in the Parameters' Space subsection below.

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<sup>26</sup>Other BTA papers in the literature also had to address this issue (BTA Constraint) in order for the analysis to be valid, albeit they followed different strategies to suit their model setup. For example check Eyland and Zaccour (2012 & 2014).

### 6.4.2 BTA Constraints

Although the BTA constraints are not required for the No BTA regime we note the following. In Proposition 3 in Finus and Al Khourdajie (2017), it was established analytically that for  $\gamma = 1$  it is always the case that  $t_i^* > t_j^*$ . For  $\gamma = 0$  we have  $t_i^* > t_j^*$  only for  $a \leq \bar{a}$ , where  $\bar{a} = 2n\delta + c$ . For  $\gamma = 0.5$  we establish in this paper the threshold  $\bar{a}$  such that  $t_i^* > t_j^*$  is given by  $\bar{a} = n^2\delta + 2n\delta + c$ . The reason such threshold emerges for partial and high TFV only is that when consumers prefer varieties then above certain level of high demand (represented by the thresholds) joint maximisation of signatories calls for lowering the tax in order to maximise their consumers' welfare.

The reason we establish the “BTA constraint” for the No BTA regime is to check whether there is a level of demand (represented by an  $a$  value) under which signatories' taxes are lower than non-signatories' ones in the No BTA regime,  $t_i^{NoBTA} < t_j^{NoBTA}$ , but they become higher in the BTA regime,  $t_i^{BTA} > t_j^{BTA}$ . Such case could be interesting for comparative analysis, i.e.  $t_i^{NoBTA} < t_j^{NoBTA}$  while  $t_i^{BTA} > t_j^{BTA}$  at the same time. As we will show in the next section, the parameter  $a$  values that result into  $t_i^{NoBTA} < t_j^{NoBTA}$  violate the BTA constraint for the BTA regime. Therefore, we are unable to conduct such comparative analysis.

As for the BTA regime, we define the BTA constraints under  $\gamma = \{0, 0.5, 1\}$ . Due to the complexity of the constraints we resort to numerical simulations. Therefore, we also present the corresponding constraints for the No BTA regime in numerical values in the Parameters' Space subsection.

### 6.4.3 Parameters' Space

We populate these thresholds for both the BTA and No BTA regime under the following parameters' constellations:  $n = 10$ ,  $\gamma = \{0, 0.5, 1\}$ ,  $\delta = \{10, 50, 100\}$ ,  $c = 0$ ,<sup>27</sup> and full adjustment  $\phi = 1$ .

The No BTA regime's non-negativity constraints  $\underline{a}$  and the thresholds for  $t_i^* > t_j^*$ , i.e.  $\bar{a}$ , are given by:

	$\delta = 10$		$\delta = 50$		$\delta = 100$	
	$\underline{a}$	$\bar{a}$	$\underline{a}$	$\bar{a}$	$\underline{a}$	$\bar{a}$
$\gamma = 0$	101	200	501	1000	1001	2000
$\gamma = 0.5$		1200		6000		12000
$\gamma = 1$		$\infty$		$\infty$		$\infty$

<sup>27</sup>Since we have constant marginal costs symmetric across all firms (signatories' and non-signatories' ones) such simplification will not affect our qualitative results.

The BTA regime's non-negativity constraints  $\underline{a}$  and BTA constraints  $\bar{a}$  are given by:<sup>28</sup>

	$\delta = 10$		$\delta = 50$		$\delta = 100$	
	$\underline{a}$	$\bar{a}$	$\underline{a}$	$\bar{a}$	$\underline{a}$	$\bar{a}$
$\gamma = 0$	85	104	430	520	850	1040
$\gamma = 0.5$	120	1000	590	5300	1250	10500
$\gamma = 1$	250	$\infty$	1350	$\infty$	2500	$\infty$

Notice that for  $\gamma = 1$  it turns out that  $\bar{a} = \infty$  for the BTA regime, inline with the analytical finding for the No BTA regime from Finus and Al Khouradajie (2017).

#### 6.4.4 Analysis Strategy

We proceed in the analysis by creating a joint BTA and No BTA parameters' space such that both constraints are satisfied in both regime (i.e.  $\underline{a} < a \leq \bar{a}$ ) in order to be able to undertake comparative analysis. The joint parameters' space for both regimes is as follows:

	$\delta = 10$		$\delta = 50$		$\delta = 100$	
	$\underline{a}$	$\bar{a}$	$\underline{a}$	$\bar{a}$	$\underline{a}$	$\bar{a}$
$\gamma = 0$	101	104	501	520	1001	1040
$\gamma = 0.5$	120	1000	590	5300	1250	10500
$\gamma = 1$	250	5000	1350	25000	2500	50000

Notice that in order to put an upper limit on the BTA constraint under  $\gamma = 1$  (where  $\bar{a} = \infty$ ), we multiply the BTA constraint under  $\gamma = 0.5$  by 5 (approx.) to set the limit.<sup>29</sup>

In order to cover the whole parameters' space, we break each range (for each  $\delta$  and  $\gamma$  combination) into 5 equidistant points using the interval  $\Delta = \frac{\bar{a}-\underline{a}}{5}$ . The value of  $a$  at each point would be given by  $a_i = a_{i-1} + \Delta$  for  $i = 1, \dots, 5$ . For instance:  $a_1 = \underline{a} + \Delta$  and  $a_5 = a_4 + \Delta \leq \bar{a}$ . The value for these equidistant points for the joint BTA and No BTA parameters space are:

<sup>28</sup>For full range of  $\gamma = [0, 1]$ , check below.

<sup>29</sup>Given our findings in Appendix 6 below we can confirm that we are not eliminating any qualitative results by following such strategy to set an upper threshold  $\bar{a}$  for  $\gamma = 1$ .

	$\delta = 10$	$\delta = 50$	$\delta = 100$	Value
	$a$	$a$	$a$	$a$
$\gamma = 0$	101.6	504.8	1008.8	Low - L
	102.2	508.4	1016.6	Lower Middle - LM
	102.8	512.4	1024.5	Middle - M
	103.4	516.2	1032.2	Upper Middle - UM
	104	520	1040	High - H
$\gamma = 0.5$	296	1532	3100	Low - L
	472	2474	4950	Lower Middle - LM
	648	3416	6800	Middle - M
	824	4358	8650	Upper Middle - UM
	1000	5300	10500	High - H
$\gamma = 1$	1200	6080	12000	Low - L
	2150	10810	21500	Lower Middle - LM
	3100	15540	31000	Middle - M
	4050	20270	40500	Upper Middle - UM
	5000	25000	50000	High - H

## 6.5 Appendix 5: Non-negativity Constraints for the No BTA Scenario

Inserting the equilibrium taxes of the No BTA regime into equilibrium output levels, gives the quantities below.

- For  $\gamma = 1$ :

$$q_i^* = \frac{(a - c)}{n} - \frac{\delta(n^2(m - 1) - n(m - 1)^2 - m(m - 2))}{m(n^2 + (1 - m)(n + 1))}$$

$$q_j^* = \frac{(a - c)}{n} + \frac{\delta n(n(m - 1) + m - 2)}{n(n^2 + (1 - m)(n + 1))}$$

- For  $\gamma = 0.5$ :

$$q_i^* = \frac{2n(a - c)(n(2n^2 + 10n + 9) + nm(2 - 2m) + m(9 - 6m) - 9)}{n(2n^4 + 14n^3 + n^2(32 - 2m^2 - m) + n(18 - 7m^2 - 5m) - 3m^2 - 9m - 18) + 9m}$$

$$+ \frac{2n\delta(3n(n^2 + 3n) + nm(-3n^2 + 3nm - 18n + 9m - 27) + 9m)}{n(2n^4 + 14n^3 + n^2(32 - 2m^2 - m) + n(18 - 7m^2 - 5m) - 3m^2 - 9m - 18) + 9m}$$

$$q_{.j}^* = \frac{2n(a-c)(2n^3 - 2nm^2 + 10n^2 - nm - 6m^2 + 12n)}{n(2n^4 + 14n^3 + n^2(32 - 2m^2 - m) + n(18 - 7m^2 - 5m) - 3m^2 - 9m - 18) + 9m}$$

$$+ \frac{2n\delta(3n^2m^2 - 3n^2m + 9nm^2 - 6n^2 - 9nm - 18n + 9m)}{n(2n^4 + 14n^3 + n^2(32 - 2m^2 - m) + n(18 - 7m^2 - 5m) - 3m^2 - 9m - 18) + 9m}$$

- For  $\gamma = 0$ :

$$q_{.i}^* = \frac{n(a - c - \delta m)}{2n - m}$$

$$q_{.j}^* = \frac{n(a - c - \delta)}{2n - 1}$$

These equilibrium quantities reveal the need for non-negativity conditions to be imposed to guarantee firms are producing positive quantities. Essentially, these constraints boil down to requesting that the demand parameter  $a$  is larger than marginal production cost  $c$  plus a multiple of marginal damages.

- For  $\gamma = 1$ : signatories' non-negativity constraint is given by  $a > \underline{a}_1 = \frac{\delta n(n^2(m-1) - n(m-1)^2 - m(m-2))}{m(n^2 + (1-m)(n+1))} + c$ , and non-signatories' constraint is given by  $a > \underline{a}_2 = c$ , with  $\underline{a}_1 > \underline{a}_2$ .
- For  $\gamma = 0.5$ : signatories' non-negativity constraint is given by  $a > \underline{a}_3 = c - \frac{\delta(0.375n^2(n-nm+m^2)+1.125(n^2(1-2m)+m(nm-3n+1)))}{0.25(n(n^2+m-m^2)-3m^2)+1.125(n+m-1)+1.25n^2}$ , and non-signatories' constraint is given by  $a > \underline{a}_4 = c - \frac{\delta(0.75(n^2(0.5(m^2-m)-1))+1.125(n(m^2-2)+m(1-n)))}{0.25(n(n^2+5n+6)-m(nm+0.5n+3m))}$ , with  $\underline{a}_3 > \underline{a}_4$ .
- For  $\gamma = 0$ : signatories' non-negativity constraint is given by  $a > \underline{a}_5 := \delta m + c$ , and non-signatories' constraint is given by  $a > \underline{a}_6 := \delta + c$ , with  $\underline{a}_5 > \underline{a}_6$ .

It can be shown that  $\underline{a}_l > 0$ ,  $\forall l \in [1, 6]$ . Notice that for  $\gamma = \{0, 0.5, 1\}$ ,  $\frac{\partial \underline{a}_1}{\partial m} > 0$ ,  $\frac{\partial \underline{a}_3}{\partial m} > 0$ , and  $\frac{\partial \underline{a}_5}{\partial m} > 0$ . Therefore, the most restrictive non-negativity constraint for any of them can be found for  $m = n$ , where  $\underline{a}_1 = \underline{a}_3 = \underline{a}_5 = n\delta + c$ . Throughout the paper, we assume the most restrictive constraint to hold.



## 6.6 Appendix 6: Detailed Results

### Low $a$ Value

#### Result 2 - Welfare Properties of the No BTA and BTA Coalition Games - Low $a$ Value

BTA Regime<sup>30</sup>

$\gamma$	$\delta$	$W_i^{BTA} - W_j^{BTA}$	Externality	I Spillover	SAD	FC	C
1	$\forall \delta$	+	−	$+, \forall m = [2, 6]$	+	$+, \forall m = [2, 6]$	+
0.5	$\forall \delta$	+	$-, \forall m = [3, 4]$	$+, \forall m = [2, 8]$	+	+	+
0	$\forall \delta$	$+, \forall m = [2, 4]$	+	+	+	+	+

No BTA Regime

$\gamma$	$\delta$	$W_i^{NoBTA} - W_j^{NoBTA}$	Externality	I Spillover	SAD	FC	C
1	$\forall \delta$	−	+	$-, \forall m = [2, 5]$	$-, \forall m = [2, 9]$	+	+
0.5	$\forall \delta$	−	+	+	+	+	+
0	$\forall \delta$	−	+	+	+	+	+

#### Result 3 - Coalitions under Internal and External Stability - Low $a$ Value

BTA Regime	$\gamma$	$\delta = 10$	$\delta = 50$	$\delta = 100$
I&ES	1	$m^* = 10$	$m^* = 10$	$m^* = 10$
	0.5	$m^* = 10$	$m^* = 10$	$m^* = 10$
	0	$m^* = 9$	$m^* = 9$	$m^* = 9$

<sup>30</sup>Whenever a result is presented in an interval format such as  $+, \forall m = [1, 4]$ , this implies that  $\forall m = [1, 4]$  the property is positive/holds and  $\forall m = [5, 10]$  the property is negative/fails.

<sup>31</sup>Legend: I Spillover: Internal Spillover. SAD: Superadditivity. FC: Full Cohesiveness. The entry of “+”: implies holds or positive (depending on the property). The input of “−”: fails or negative.

No BTA Regime	$\gamma$	$\delta = 10$	$\delta = 50$	$\delta = 100$
I&ES	1	$m^* = 1$	$m^* = 1$	$m^* = 1$
	0.5	$m^* = 2$	$m^* = 2$	$m^* = 2$
	0	$m^* = 3$	$m^* = 3$	$m^* = 3$

#### Result 4 - Coalitions under Exclusive Membership - Low $a$ Value

BTA Regime	$\gamma$	$\delta = 10$	$\delta = 50$	$\delta = 100$
Exclusive	1	$m^* = 6$	$m^* = 6$	$m^* = 6$
	0.5	$m^* = 8$	$m^* = 8$	$m^* = 8$
	0	$m^* = 9$	$m^* = 9$	$m^* = 9$

#### Lower Middle $a$ Value

#### Result 2 - Welfare Properties of the No BTA and BTA Coalition Games - Lower Middle $a$ Value

BTA Regime

$\gamma$	$\delta$	$W_i^{BTA} - W_j^{BTA}$	Externality	I Spillover	SAD	FC	C
1	$\forall \delta$	+	−	$+, \forall m = [2, 6]$	+	$-, \forall m = [5, 8]$	+
0.5	10	+	$-, \forall m = [3, 9]$	$+, \forall m = [2, 6]$	+	$-\forall m = [7, 8]$	+
	50					$-\forall m = [6, 8]$	
	100						
0	$\forall \delta$	$+, \forall m = [2, 4]$	+	+	+	+	+

No BTA Regime

$\gamma$	$\delta$	$W_i^{NoBTA} - W_j^{NoBTA}$	Externality	I Spillover	SAD	FC	C
1	$\forall \delta$	—	+	$-, \forall m = [2, 5]$	$-, \forall m = [2, 9]$	+	+
0.5	$\forall \delta$	—	+	+	+	+	+
0	$\forall \delta$	—	+	+	+	+	+

**Result 3 - Coalitions under Internal and External Stability - Lower Middle  $a$  Value**

BTA Regime	$\gamma$	$\delta = 10$	$\delta = 50$	$\delta = 100$
I&ES	1	$m^* = 10$	$m^* = 10$	$m^* = 10$
	0.5	$m^* = 10$	$m^* = 10$	$m^* = 10$
	0	$m^* = 8$	$m^* = 8$	$m^* = 8$

No BTA Regime	$\gamma$	$\delta = 10$	$\delta = 50$	$\delta = 100$
I&ES	1	$m^* = 1$	$m^* = 1$	$m^* = 1$
	0.5	$m^* = 2$	$m^* = 2$	$m^* = 2$
	0	$m^* = 3$	$m^* = 3$	$m^* = 3$

**Result 4 - Coalitions under Exclusive Membership - Lower Middle  $a$  Value**

BTA Regime	$\gamma$	$\delta = 10$	$\delta = 50$	$\delta = 100$
Exclusive	1	$m^* = 6$	$m^* = 6$	$m^* = 6$
	0.5	$m^* = 6$	$m^* = 6$	$m^* = 6$
	0	$m^* = 8$	$m^* = 8$	$m^* = 8$

### Middle $a$ Value

#### Result 2 - Welfare Properties of the No BTA and BTA Coalition Games - Middle $a$ Value

##### BTA Regime

$\gamma$	$\delta$	$W_i^{BTA} - W_j^{BTA}$	Externality	I Spillover	SAD	FC	C
1	$\forall \delta$	+	−	$+, \forall m = [2, 5]$	+	$-, \forall m = [4, 8]$	+
0.5	$\forall \delta$	+	$-, \forall m = [2, 8]$	$+, \forall m = [2, 6]$	+	$-, \forall m = [4, 8]$	+
0	$\forall \delta$	$+, \forall m = [2, 4]$	+	+	+	+	+

##### No BTA Regime

$\gamma$	$\delta$	$W_i^{NoBTA} - W_j^{NoBTA}$	Externality	I Spillover	SAD	FC	C
1	$\forall \delta$	−	+	$-, \forall m = [2, 5]$	$-, \forall m = [2, 9]$	+	+
0.5	$\forall \delta$	−	+	+	+	+	+
0	$\forall \delta$	−	+	+	+	+	+

#### Result 3 - Coalitions under Internal and External Stability - Middle $a$ Value

BTA Regime	$\gamma$	$\delta = 10$	$\delta = 50$	$\delta = 100$
I&ES	1	$m^* = 10$	$m^* = 10$	$m^* = 10$
	0.5	$m^* = 10$	$m^* = 10$	$m^* = 10$
	0	$m^* = 9$	$m^* = 9$	$m^* = 8$

No BTA Regime	$\gamma$	$\delta = 10$	$\delta = 50$	$\delta = 100$
I&ES	1	$m^* = 1$	$m^* = 1$	$m^* = 1$
	0.5	$m^* = 2$	$m^* = 2$	$m^* = 2$
	0	$m^* = 3$	$m^* = 3$	$m^* = 3$

**Result 4 - Coalitions under Exclusive Membership - BTA Regime - Middle  $a$  Value**

BTA Scenario	$\gamma$	$\delta = 10$	$\delta = 50$	$\delta = 100$
Exclusive	1	$m^* = 5$	$m^* = 5$	$m^* = 5$
	0.5	$m^* = 6$	$m^* = 6$	$m^* = 6$
	0	$m^* = 9$	$m^* = 9$	$m^* = 8$

**Upper Middle  $a$  Value**

**Result 2 - Welfare Properties of the No BTA and BTA Coalition Games - Upper Middle  $a$  Value**

BTA Regime

$\gamma$	$\delta$	$W_i^{BTA} - W_j^{BTA}$	Externality	I Spillover	SAD	FC	C
1	$\forall \delta$	+	—	$+, \forall m = [2, 5]$	+	$-, \forall m = [3, 8]$	+
0.5	$\forall \delta$	+	$-, \forall m = [2, 8]$	$+, \forall m = [2, 5]$	+	$-, \forall m = [2, 7]$	+
0	$\forall \delta$	$+, \forall m = [2, 4]$	+	+	+	+	+

No BTA Regime

$\gamma$	$\delta$	$W_i^{NoBTA} - W_j^{NoBTA}$	Externality	I Spillover	SAD	FC	C
1	$\forall \delta$	—	+	$-, \forall m = [2, 5]$	$-, \forall m = [2, 9]$	+	+
0.5	$\forall \delta$	—	+	+	+	+	+
0	$\forall \delta$	—	+	+	+	+	+

**Result 3 - Coalitions under Internal and External Stability - Upper Middle  $a$  Value**

BTA Regime	$\gamma$	$\delta = 10$	$\delta = 50$	$\delta = 100$
I&ES	1	$m^* = 10$	$m^* = 10$	$m^* = 10$
	0.5	$m^* = 10$	$m^* = 10$	$m^* = 10$
	0	$m^* = 9$	$m^* = 9$	$m^* = 9$

No BTA Regime	$\gamma$	$\delta = 10$	$\delta = 50$	$\delta = 100$
I&ES	1	$m^* = 1$	$m^* = 1$	$m^* = 1$
	0.5	$m^* = 2$	$m^* = 2$	$m^* = 2$
	0	$m^* = 3$	$m^* = 3$	$m^* = 3$

**Result 4 - Coalitions under Exclusive Membership - BTA Regime - Upper Middle  $a$  Value**

BTA Regime	$\gamma$	$\delta = 10$	$\delta = 50$	$\delta = 100$
Exclusive	1	$m^* = 5$	$m^* = 5$	$m^* = 5$
	0.5	$m^* = 5$	$m^* = 5$	$m^* = 5$
	0	$m^* = 9$	$m^* = 9$	$m^* = 9$

**High  $a$  Value**

**Result 2 - Welfare Properties of the No BTA and BTA Coalition Games - High  $a$  Value**

BTA Regime

$\gamma$	$\delta$	$W_i^{BTA} - W_j^{BTA}$	Externality	I Spillover	SAD	FC	C
1	$\forall \delta$	+	-	$+, \forall m = [2, 5]$	+	$-, \forall m = [2, 8]$	+
0.5	$\forall \delta$	+	$-, \forall m = [2, 8]$	$+, \forall m = [2, 5]$	+	$-, \forall m = [2, 7]$	+
0	$\forall \delta$	$+, \forall m = [2, 5]$	+	+	+	+	+

No BTA Regime

$\gamma$	$\delta$	$W_i^{NoBTA} - W_j^{NoBTA}$	Externality	I Spillover	SAD	FC	C
1	$\forall \delta$	-	+	$-, \forall m = [2, 5]$	$-, \forall m = [2, 9]$	+	+
0.5	$\forall \delta$	-	+	+	+	+	+
0	$\forall \delta$	-	+	+	+	+	+

**Result 3 - Coalitions under Internal and External Stability - High  $a$  Value**

BTA Regime	$\gamma$	$\delta = 10$	$\delta = 50$	$\delta = 100$
I&ES	1	$m^* = 10$	$m^* = 10$	$m^* = 10$
	0.5	$m^* = 10$	$m^* = 10$	$m^* = 10$
	0	$m^* = 9$	$m^* = 9$	$m^* = 9$

No BTA Regime	$\gamma$	$\delta = 10$	$\delta = 50$	$\delta = 100$
I&ES	1	$m^* = 1$	$m^* = 1$	$m^* = 1$
	0.5	$m^* = 2$	$m^* = 2$	$m^* = 2$
	0	$m^* = 3$	$m^* = 3$	$m^* = 3$

**Result 4 - Coalitions under Exclusive Membership - BTA Regime - High  $a$  Value**

BTA Regime	$\gamma$	$\delta = 10$	$\delta = 50$	$\delta = 100$
Exclusive	1	$m^* = 5$	$m^* = 5$	$m^* = 5$
	0.5	$m^* = 5$	$m^* = 5$	$m^* = 5$
	0	$m^* = 9$	$m^* = 9$	$m^* = 9$



## Part VII

# Paper 3: Joint Climate Change and Customs' Union Agreements under Consumers' Taste for Variety



# Joint Climate Change and Customs' Union Agreements under Consumers' Taste for Variety

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(Preliminary version - please do not quote)

## Abstract

In an  $n$ -country intra-industry trade model governments deal with two issues: climate change and trade. Firms produce a horizontally differentiated good and consumers have a taste for the varieties of this good. We analyse coalition formation and stability under three scenarios where governments are either cooperating on one issue only or on both issues at the same time. Our results show that whenever governments cooperate on trade, either individually or with climate change, the grand coalition is always stable. More interestingly, we find that when governments cooperate on climate change only the grand coalition is also stable. However, this holds only when varieties are perfect substitutes.

Keywords: self-enforcing international environmental agreements, international trade, customs' unions, consumers' preferences, horizontal products' differentiation.

JEL Classification: C72, F12, F18, H23, Q52, Q56, Q58.

# 1 Introduction

Reaching international agreements on climate change has proved to be a difficult task over the past two and half decades. One of the most notable achievements of the climate change negotiations thus far is Paris Climate Agreement, signed in December 2015. This agreement aims to achieve the scientifically recommended target of limiting the temperature increase by the year 2100 to 2 degrees Celsius compared to pre-industrial levels. However, despite agreeing on this target, signatories' current emission reduction pledges fall short of meeting it and will potentially yield a temperature increase of 2.7-3 degrees Celsius (UNFCCC, 2015). Furthermore, the agreement fails to bind signatories to meet their pledges.

Scholars in the game theoretic literature on the formation of international environmental agreements (IEAs) attribute the difficulty in reaching an effective climate change agreement to strong free-riding incentives. These incentives emerge due to the fact that any non-signatory would enjoy the environmental benefits resulting from signatories' emissions reduction efforts without incurring any costs. Therefore, given the absence of supranational authority that could enforce cooperation on climate change, any stable agreement has to be self-enforcing. Findings in this literature show that this free riding phenomenon has either led to agreements with few signatories and/or with very low and hence ineffective emission reduction targets. In other words, these agreements are either small, shallow or both (see Barrett, 1994a; and Finus, 2003 for surveys).

In order to overcome such pessimistic predictions, further contributions in the literature followed different strategies such as analysing various policy instruments, markets' structures or trade features. The main objective of this paper is to address the case of issue linkage between climate change agreements and customs' union agreements. That is, we analyse a joint climate change and customs' union agreement. While climate agreements suffer from strong free riding incentives due to positive externalities, customs' unions are identified as club good agreements where benefits are exclusive to signatories only (Yi, 1996). Accessing these benefits may give countries an incentive to join the joint agreement. Furthermore, customs' unions exhibit spillovers toward non-signatories, whereby if these spillovers are negative they create an additional incentive for cooperation.

In order to setup the joint agreement, this paper essentially combines the setup of two papers. The first is Finus and Al Khourdajie (2017) representing the climate change agreement and the second is Yi (1996) representing the customs' union agreement. In Finus and Al Khourdajie (2017) the authors introduce horizontal products' differentiation and consumers' taste for variety (TFV) to the literature of IEAs under free trade. By introducing such features consumers' tastes and preferences matter and hence they influence governments' decisions in terms of coalition membership and level of emission taxes. The authors find that high consumers' TFV gives the incentives for forming a small climate change agreement. Their findings are inline

with the literature in terms of size of the agreement being small due to free riding incentives. Therefore, emission taxes as first best solution did not help in reaching the grand coalition. In Yi (1996) the author analyses customs' unions (with no environmental aspect) that deploy the use of trade tariffs. In his setup, the author examines the effects of horizontal products' differentiation and consumers' TFV on coalition stability in a multiple coalition formation game. The author finds that the incentives to join customs' unions are strong leading to the stability of the grand coalition.<sup>32</sup>

In the literature on issue linkage, the majority of current contributions examine linking IEAs with research and development (R&D) agreements and show that such linkage leads to higher contribution to the environmental agreement. For instance Botteon and Carraro (1997) find that the free riding incentives under IEAs are mitigated by the incentives of accessing the R&D benefits within the coalition. Carraro and Siniscalco (1997) show that this is true even if the R&D benefits are imperfectly excludable (i.e. the inevitable leakage to non-signatories through reverse engineering for instance). Katsoulacos (1997) allows for governments to engage in subsidising Research Joint Ventures (RJV) initiatives and finds that this induces higher contribution to the environmental issue. However, Kemfert (2004) analyses a similar joint agreement in an integrated assessment model and finds that, unsurprisingly, issue linkage fails to completely mitigate free riding incentives when positive externalities are very strong. Finally, Carraro and Marchiori (2004) argue that the number of participants in the joint agreement is always smaller than or equal to the number of participants in the original R&D club good agreement. They show that while benefits from the public good agreement are always monotonically increasing in the number of participants, benefits from the club good agreement have an incomplete monotonicity. We contribute to this literature by analysing joint cooperation in an  $n$ -country model under international trade with consumers' taste for varieties.

Some contributions in this literature analysed issue linkage with trade agreements. For instance, Nordhaus (2015) uses the Coalition DICE model (the Coalition Dynamic Integrated Climate-Economy model) to study the stability of climate clubs: under which signatories of a climate agreement can impose trade penalties on imports from non-signatories. In line with the literature, the author finds that the use of trade penalties leads to the stability of large coalitions. Kuhn et al. (2015) follow Eichner and Pethig's (2013) perfect competition framework and analyse the effects of issue linkage between climate agreements that use emissions caps and free trade areas. The authors find that such issue linkage mitigates the free riding incentives leading to the grand coalition. Our paper contributes to this body of literature by analysing the effects of consumers' TFV under imperfect competition where countries use emission taxes and trade tariffs as policy instruments.

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<sup>32</sup>Check Yi's (2000) analysis of free trade area formation and stability, and Loke and Winters (2012) for detailed analysis of the TFV feature in the context of Yi's papers.

Another body of literature assesses the conditions under which larger and more effective IEAs could form under the international trade comparing to autarky. Extending Barrett's (1994b) IEAs autarky model to the case of international trade under perfect competition, Eichner and Pethig (2013) show that large coalitions could be stable under Stackelberge coalition formation games comparing to small coalitions under Nash Cournot games as in E&P (2012). However, they find that the emission reduction efforts of these large coalitions are negligible. In E&P (2014a) the authors show that the introduction of emission taxes could lead to the stability of the grand coalition. The reason for this is that they find taxes are strategic complements while caps are strategic substitutes and hence free riding is stronger under caps. Some contributions in this literature strand address the implications of using trade bans as an additional policy instrument in the climate agreement and show that such policy leads to large and more effective agreements (Barrett, 1997; and E&P, 2014b).

Our model is an extension of Brander and Spencer (1985) framework where we assume *n ex ante* symmetric countries. Governments have two policy instruments. First, they can impose emission taxes on their domestic firm's production in order to reduce pollution damages. Second, they can impose trade tariffs on imports. Each government is concerned with the domestic firm's profit, revenues from emission taxes and trade tariffs, the utility of the domestic consumers and finally the environmental damages resulting from a global pollutant. Each firm produces a unique variety of a horizontally differentiated good and consumers have taste for these varieties (Yi, 1996).

In this setup we examine the effects of issue linkage between climate change and customs' union agreements in influencing countries' decisions on their taxes and tariffs as well as coalition membership. We analyse three scenarios. The first is called environmental cooperation scenario, where signatories coordinate their climate policy and set their emission taxes collectively in order to maximise the joint welfare of the whole coalition. As for the trade policy, they neither coordinate their trade tariffs, nor abolish them within the coalition. The second scenario is called trade cooperation scenario, where signatories coordinate their trade tariffs only, i.e. cooperate on trade and form a customs' union, with no coordination of climate policy; emission taxes. In this scenario, signatories abolish trade tariffs within the coalition and impose tariffs on imports from non-signatories to maximise the joint welfare of the coalition. As for the climate policy, each signatory chooses an emissions tax that maximises its own welfare. The third scenario is called joint cooperation, which is essentially a combination of both previous scenarios illustrating the case of issue linkage. Signatories coordinate both their trade tariffs and emission taxes, i.e. forming a joint climate change and customs' union agreement. In this scenario, signatories abolish trade tariffs within the coalition and impose tariffs on imports from non-signatories to maximise the joint welfare of the coalition. They also jointly choose a uniform emission tax that maximises the joint welfare of the coalition. In all three scenarios non-signatories choose their own emission taxes and trade tariffs in order

to maximise their individual welfare.

For analytic tractability, we focus on two cases of taste for varieties (TFV). The first is where consumers have no TFV and hence varieties are considered perfect substitutes. The second case is where taste for varieties is high and hence varieties are independent and consumers have a high preference for a diverse and balanced consumption bundle since varieties cannot be substituted at all.

Our results present new insights into environmental cooperation when governments are dealing with more than one issues, namely climate change and free trade in our context, and have two policy instruments to deal with them. In the case where consumers have no taste for varieties, i.e. varieties are perfect substitutes following the standard assumption in the literature, we find the incentives for cooperation on climate change are strong when countries coordinate their emission taxes even though they do not coordinate their trade policy. That is, providing signatories with an additional policy instrument, such as trade tariffs that can be imposed on all imports, makes them more powerful in the sense of having the ability to generate additional revenues as well as pose negative externalities toward non-signatories. These driving forces together lead to the stability of the grand coalition. Unfortunately, when varieties become independent the incentives for forming large coalitions breakdown. The fact that signatories have an additional policy instrument does not help with the stability of large coalitions when varieties are independent and we find only small coalitions are stable in equilibrium. A more detailed discussion on these findings is presented later in the paper.

As for the trade cooperation scenario, we find that the exclusive benefits of free trade and the negative externalities posed toward non-signatories are both providing the incentives for cooperation leading to the stability of the grand coalition irrespective of consumers' taste for variety. These driving forces also carry over when signatories form a joint agreement and coordinate both their emission taxes and trade tariffs leading to the grand coalition to be stable in equilibrium. In relating these results to the current literature, while the incentives for forming climate change coalitions are not strong enough due to positive externalities (Finus and Al Khourdjie, 2017), the incentives for forming customs' unions are stronger given the benefits of joining the coalition and the incentives to avoid negative externalities (Yi, 1996). In our environmental cooperation scenario we show that proving signatories with additional policy instrument might sometimes lead to strong incentive for cooperation. As for our joint cooperation scenario, we show that the joint agreement combines both features of strong incentives for cooperation brought about by the customs' unions as well as the policy instrument to deal with the damages' externality.

The paper proceeds as follows. In section 2 we present the model. In section 3 we present and discuss the results. In section 4 we conclude.

## 2 Model

### 2.1 Payoff Function

Consider an intra-industry trade model of  $n$  *ex ante* symmetric countries with a representative firm and consumer in each country. We denote the set of countries by  $N$ . Firms produce a horizontally differentiated good, i.e. the same good but in different varieties where each firm produces one unique variety. Firms compete in a Cournot-fashion. Markets are segmented and each firm supplies its good to the domestic and all foreign markets. Given markets' segmentation, firms play a separate Cournot game in each market.<sup>33</sup> Transport costs are assumed away as usual.

The welfare of a country  $i$  is given by:

$$W_i = CS_i + PS_i + TR_i + \tau R_i - D_i \quad (1)$$

where  $CS_i$  represents country  $i$ 's consumer surplus,  $PS_i$  country  $i$ 's producer surplus,  $TR_i$  country  $i$ 's emission tax revenue from the tax imposed by each government on its domestic firm's production,  $\tau R_i$  country  $i$ 's trade tariffs revenue from the tariffs imposed by each government on all imports, and finally  $D_i$  represents the pollution damages faced by country  $i$ .

Consumers are identical with a quasilinear utility function over two goods. The first good is the horizontally differentiated and traded good. The second good is a numeraire good, representing the composition of all other goods. Utility is linear in the numeraire good and quadratic in the differentiated good. We assume that consumers have a taste for the variety of the differentiated good (Dixit and Stiglitz, 1977). That is, consumers' utility depends not only on the total quantity consumed but also on the composition of quantities of the differentiated good. To capture all these features, we use the representative consumer's utility function presented in Yi (1996), where for a country  $i$  consumers' utility  $u_i$  is given by:

$$u_i(q_i; M_i) = v_i(q_i) + M_i = aQ_i - \frac{\gamma}{2}Q_i^2 - \frac{1-\gamma}{2} \sum_{k \in N} q_{ik}^2 + M_i \quad (2)$$

where  $v_i$  represents the utility from consuming the horizontally differentiated and traded good and  $M_i$  represents the utility from consuming the numeraire good;  $q_i = (q_{i1}, \dots, q_{in})$  is a vector of the varieties consumed by consumers in country  $i$  that are produced by all firms, with  $q_{ik}$  representing country  $i$ 's consumption of country  $k$ 's variety;<sup>34</sup>  $a$  is a positive demand parameter and  $Q_i = \sum_{k \in N} q_{ik}$  is country  $i$ 's total consumption of all varieties, supplied by all countries  $k$ . Consumers' taste for

<sup>33</sup>See Appleyard and Field (2014) as well as Helpman and Krugman (1985) for further background.

<sup>34</sup>Throughout the paper the first subscript indicates the market in which the variety is consumed and the second subscript indicates the market in which it is produced.



variety (abbreviated TFV hereafter) is captured by parameter  $\gamma \in [0, 1]$ . High values of  $\gamma$  imply a low taste for varieties and for  $\gamma = 1$  varieties are perfect substitutes. In contrast, low values of  $\gamma$  represent a high preference for a diverse and balanced consumption bundle and for  $\gamma = 0$  varieties cannot be substituted at all.<sup>35</sup> In this paper, in most parts, we will focus our analysis on two TFV cases for analytic tractability: no TFV with  $\gamma = 1$  and full TFV with  $\gamma = 0$ .

From (2), country  $i$ 's inverse demand function for any country  $k$ 's variety follows from:

$$p_{ik} = \frac{\partial u_i}{\partial q_{ik}} \iff p_{ik} = a - (1 - \gamma)q_{ik} - \gamma Q_i. \iff p_{ik} = a - q_{ik} - \gamma \sum_{l \in N, l \neq k} q_{il} \quad (3)$$

where  $p_{ik}$  represents the price faced by consumers in country  $i$  consuming the variety of country  $k$ , and  $\sum_{l \in N, l \neq k} q_{il}$  is the sum of all consumed varieties produced by all firms except firm  $k$ .

From (2) and (3), the representative consumer surplus in country  $i$  is given by:

$$CS_i = aQ_i - \frac{\gamma}{2}Q_i^2 - \frac{1 - \gamma}{2} \sum_{k \in N} q_{ik}^2 - \sum_{k \in N} q_{ik}p_{ik} \quad (4)$$

where the last term in (4) represents consumers' spending.

The emission tax revenue for country  $i$  is given by:

$$TR_i = t_i \sum_{k \in N} q_{ki} \quad (5)$$

The trad tariff revenue for country  $i$  is given by:

$$\tau R_i = \tau_i \sum_{l \in N, l \neq i} q_{il} \quad (6)$$

where  $\sum_{l \in N, l \neq i} q_{il}$  represents consumption of all varieties in market  $i$  except the domestically produced one by firm  $i$ , i.e. consumption of all imports.

The damages from global pollution faced by country  $i$  are given by:

$$D_i = \delta \sum_{k \in N} Q_k. \quad (7)$$

where  $\delta$  is a damage parameter,  $\sum_{k \in N} Q_k$  is total consumption in every country  $k$  and hence total emissions (due to our assumption of a constant emission to output

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<sup>35</sup> An extension could be the "ideal variety" approach where consumers have not only a general preference for the variety of the good but also a preference for a particular variety. One application is a bias towards the domestically produced variety (Di Comite *et al.*, 2014).

coefficient of 1). That is, emissions constitute a pure public bad and hence damages depend on total emissions.

Producer surplus for country  $i$ 's firm is the sum of its profit in each market:

$$PS_i = \pi_{ii} + \sum_{l \in N, l \neq i} \pi_{li} = q_{ii}(p_{ii} - c - t_i) + \sum_{l \in N, l \neq i} q_{li}(p_{li} - c - t_i - \tau_l) \quad (8)$$

where  $\pi_{ii}$  ( $\pi_{li}$ ) represents firm  $i$ 's profit in its domestic market  $i$  (in all other countries' markets  $l \in N, l \neq i$ ) from selling quantity  $q_{ii}$  ( $q_{li}$ ) at price  $p_{ii}$  ( $p_{li}$ ),  $c$  is constant marginal cost,  $t_i$  is the emission tax imposed by country  $i$ 's government on its firm's total production, and  $\tau_l$  is the per-unit trade tariff that firm  $i$  faces for its exports to each markets  $l \in N, l \neq i$ .

## 2.2 Coalition Formation Game

We assume a three-stage coalition formation game, which unfolds as follows.

*Stage 1, Choice of Membership:* all countries decide simultaneously whether to join coalition  $S$  with  $m$  the cardinality of  $S$ . Countries which do not join  $S$  act as singletons. A typical signatory will be denoted by  $i$  ( $i \in S$ ) and a non-signatory by  $j$  ( $j \in N \setminus S$ ).

Following d'Aspremont et al. (1983), a coalition is called stable if it is internally and externally stable. Internal stability means that no signatory has an incentive to leave coalition  $S$ , whereas external stability means that no non-signatory has an incentive to join coalition  $S$ . We assume for simplicity that in the case of indifference a non-signatory joins coalition  $S$ .

Internal stability:

$$W_i(S) - W_i(S \setminus \{i\}) \geq 0 \quad \forall i \in S$$

External stability:

$$W_j(S) - W_j(S \cup \{j\}) > 0 \quad \forall j \in N \setminus S$$

*Stage 2, Choice of Policy Level:* all countries choose simultaneously their emission taxes and trade tariffs. We will discuss these choices in more details in the next section.

*Stage 3, Choice of Output:* all firms choose simultaneously and non-cooperatively their segmented market outputs by maximising their producer surplus:  $\max_{q_{1i}, \dots, q_{ni}} PS_i$

The game is solved by backwards induction.

## 2.3 Choices of Policy

As mentioned in the previous section, in the second stage of the coalition formation game all countries choose simultaneously their emission taxes and trade tariffs. In order to address the case of issue linkage between climate change agreements and customs' unions, we analyse the following three scenarios:

1. Environmental cooperation: in this scenario signatories cooperate on climate change, but they do not cooperate on trade. Therefore, the policy choices are as follows:

- Signatory countries:
  - maximise their joint welfare by choosing a common emission tax  $t_i$  implemented uniformly by all signatory countries and imposed on their domestic firms' production:  $\max_{t_i} \sum_{i \in S} W_i$
  - and maximise their individual welfare by choosing a trade tariff  $\tau_i$  imposed on imports from all countries (signatories and non-signatories):  $\max_{\tau_i} W_i$ . Notice that signatories do not abolish trade tariffs on imports from other signatories' firms and hence cooperation is limited to climate change only.
- Non-signatory countries:
  - maximise their individual welfare by choosing an emission tax  $t_j$  imposed on their domestic firm's production, as well as a trade tariff  $\tau_j$  imposed on all imports from all countries' firms:  $\max_{t_j, \tau_j} W_j$ .

2. Trade cooperation: in this scenario signatories cooperate on trade and form a customs' union, but they do not cooperate on climate change. Therefore, the policy choices are as follows:

- Signatory countries:
  - abolish trade tariffs on imports from other signatories' firms
  - maximise their joint welfare by choosing a common trade tariff  $\tau_i$  implemented uniformly by all signatory countries and imposed on imports from non-signatories' firms:  $\max_{\tau_i} \sum_{i \in S} W_i$
  - and maximise their individual welfare by choosing an emission tax  $t_i$  imposed on their domestic firm's production:  $\max_{t_i} W_i$ .
- Non-signatory countries:
  - maximise their individual welfare by choosing an emission tax  $t_j$  imposed on their domestic firm's production, as well as a trade tariff  $\tau_j$  imposed on all imports from all countries' firms:  $\max_{t_j, \tau_j} W_j$ .

3. Joint cooperation on climate change and customs' union: in this scenario signatories cooperate on both climate change and trade. Therefore, the policy choices are as follows:

- Signatory countries:
  - abolish trade tariffs on imports from other signatories' firms
  - and maximise their joint welfare by choosing a common trade tariff  $\tau_i$  implemented uniformly by all signatory countries and imposed on imports from non-signatories' firms, as well as choosing an emission tax  $t_i$  implemented uniformly in all signatory countries and imposed on their domestic firm's production:  $\max_{t_i, \tau_i} \sum_{i \in S} W_i$ .
- Non-signatory countries:
  - maximise their individual welfare by choosing an emission tax  $t_j$  imposed on their domestic firm's production, as well as a trade tariff  $\tau_j$  imposed on all imports from all countries' firms:  $\max_{t_j, \tau_j} W_j$ .

## 2.4 Properties of the Game

We define the following properties to analyse the incentive to form coalitions and the associated welfare implications.

Consider  $S \subset N$ ,  $S \neq \emptyset$ , and  $S' = S \cup \{j\}$  where  $S' \subseteq N$ :

- **Positive Externality:** in a coalition game a move from coalition  $S$  to coalition  $S'$  exhibits a (strict) positive externality if:

$$W_j(S') \geq (>) W_j(S) \quad \forall j \notin S \text{ and } j \notin S'$$

- **Negative Externality:** in a coalition game a move from coalition  $S$  to coalition  $S'$  exhibits a strict negative externality if:

$$W_j(S') < W_j(S) \quad \forall j \notin S \text{ and } j \notin S'$$

- **Superadditivity:** in a coalition game a move from coalition  $S$  to coalition  $S'$  is (strictly) superadditive if:

$$\sum_{i \in S'} W_i(S') \geq (>) \sum_{i \in S} W_i(S) + W_j(S) \quad \forall j \notin S$$

- **Cohesiveness:** a coalition game is (strictly) cohesive if:

$$\sum_{i \in N} W_i(N) \geq (>) \sum_{i \in S} W_i(S) + \sum_{j \in N \setminus S} W_j(S)$$

- **Full Cohesiveness:** in a coalition game a move from coalition  $S$  to coalition  $S'$  is (strictly) fully cohesive if:

$$\sum_{i \in S'} W_i(S') + \sum_{j \in N \setminus S'} W_j(S') \geq (>) \sum_{i \in S} W_i(S) + \sum_{j \in N \setminus S} W_j(S)$$

Superadditivity provides the incentives to join a coalition, whereas the positive externality captures the incentive to free ride. In terms of forming large stable coalitions, the two properties work in opposite directions and typically for large coalitions the positive externality effects should be dominated by the superadditivity effects. Full cohesiveness justifies the search for large stable coalitions, even if the grand coalition is not stable. Essentially, global welfare increases when the coalition is enlarged gradually and if it obtains its maximum under the grand coalition then cohesiveness holds.

## 3 Results

### 3.1 Third Stage

In this section, we derive the results for the third stage of all three scenarios. Notice that the segmented market structure is exactly the same for the trade cooperation and joint cooperation scenarios. The reason for that is in both scenarios signatories abolish the trade tariffs with the coalition. Meanwhile, the segmented market structure for the environmental cooperation scenario is different from the other two scenarios given that signatories do not abolish the trade tariffs within the coalition. We will present the equilibrium quantities for all three scenarios below as compactly as possible.

Given the segmented markets' structure, markets can be categorised into signatories' and non-signatories' markets. In a signatory's market, there are three equilibrium quantities. The first  $q_i^*$  represents the domestic firm's production for its own market.<sup>36</sup> This firm faces an emission tax only, imposed by its own government. The second equilibrium quantity  $q_{ii}^*$  represents other signatories firms' production to this signatory's market. There are two cases for  $q_{ii}^*$  depending on the scenario analysed. In the case of the environmental cooperation scenario, these firms face an emission tax imposed by their own governments as well as a trade tariff imposed on their exports to this signatory's market. Meanwhile, in the case of the other two scenarios, trade cooperation and joint cooperation, signatories abolish trade tariffs within the coalition and therefore these firms face only an emission tax imposed by their own

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<sup>36</sup>Notation: in  $q_i^*$  we used one sub-script only as the quantity represents domestic firm production for the domestic market.

governments. In other words, under trade cooperation and joint cooperation scenarios  $q_i^* = q_{ii}^*$ , given that trade tariffs are abolished within the coalition and emission taxes are implemented uniformly by all signatories. The third equilibrium quantity  $q_{ij}^*$  represents non-signatories firms' exports to this signatory's market. These firms face an emission tax imposed by their own governments as well as a trade tariff imposed on their exports to this signatory's market.

In a non-signatory's market, there are always three equilibrium quantities which are the same irrespective of the scenario analysed. The first  $q_j^*$  represents the domestic firm's production for its own market.<sup>37</sup> This firm faces an emission tax only, imposed by its own government. The second equilibrium quantity  $q_{jj}^*$  represents other non-signatories firms' exports to this non-signatory's market. These firms face an emission tax imposed by their own governments as well as a trade tariff imposed on their exports to this non-signatory's market. Finally, the third equilibrium quantity  $q_{ji}^*$  represents signatories firms' exports to this non-signatory's market. These firms face an emission tax imposed by their own governments as well as a trade tariff imposed on their exports to this non-signatory's market.

This segmented markets' structure can be illustrated in the following table:<sup>38</sup>

Segmented Markets	Signatory's Firm	Non-signatory's Firm	Total Consumption
Signatories' Market	$q_i^* \text{ \& } q_{ii}^*$	$q_{ij}^*$	$Q_i^*$
Non-signatories' Market	$q_{ji}^*$	$q_j^* \text{ \& } q_{jj}^*$	$Q_j^*$
Total Production	$Q_{.i}^*$	$Q_{.j}^*$	$\sum_{k \in N} Q_k^*$

We present these quantities below. The detailed derivations are available in Appendix 1.

We first look at signatories' markets. In the case of the environmental cooperation scenario, the equilibrium quantity that a signatory's firm produces for its domestic markets ( $q_i^*$ ) is different from the one it produces for any other signatory's market ( $q_{ii}^*$ ), given that trade tariffs are not abolished within the coalition. In which case, the domestic firm  $i$ 's variety produced for its domestic market is given by:

$$q_i^* = \frac{(a - c)(2 - \gamma) - t_i(\gamma(n - m - 1) + 2) + \gamma t_j(n - m) + \gamma \tau_i(n - 1)}{(\gamma(n - 1) + 2)(2 - \gamma)} \quad (9)$$

while its variety produced for other signatories' markets is given by:

$$q_{ii}^* = \frac{(a - c)(2 - \gamma) - t_i(\gamma(n - m - 1) + 2) + \gamma t_j(n - m) - 2\tau_i}{(\gamma(n - 1) + 2)(2 - \gamma)} \quad (10)$$

<sup>37</sup>Notation: in  $q_j^*$  we used one sub-script only as the quantity represents domestic firm production for the domestic market.

<sup>38</sup>Notation: recall that in each quantity (e.g.  $q_{ij}$ ) the first subscript indicates the market in which the variety is consumed and the second subscript indicates the market in which it is produced. In the Segmented Markets table under the Total Consumption column we replace the second subscript with a dot (e.g.  $Q_{.i}^*$ ) in order to illustrate summing total consumption irrespective of the production source. The same principle applies to the first subscript under the Total Production row.

In the case of trade cooperation and joint cooperation scenarios, trade tariffs are abolished within the coalition and therefore a signatory firm  $i$ 's variety produced for any signatory  $i$ 's market (domestic or otherwise) is given by:

$$q_i^* = q_{ii}^* = \frac{(a - c)(2 - \gamma) - t_i(\gamma(n - m - 1) + 2) + \gamma(t_j + \tau_i)(n - m)}{(\gamma(n - 1) + 2)(2 - \gamma)} \quad (11)$$

Check Appendix 1 for further justifications.

In the case of environmental cooperation scenario, a non-signatory firm  $j$ 's variety produced for a signatory  $i$ 's market is given by:

$$q_{ij}^* = \frac{(a - c)(2 - \gamma) - t_j(\gamma(m - 1) + 2) + \gamma mt_i - 2\tau_i}{(\gamma(n - 1) + 2)(2 - \gamma)} \quad (12)$$

while in the case of trade cooperation and joint cooperation scenarios, it is given by:

$$q_{ij}^* = \frac{(a - c)(2 - \gamma) - (t_j + \tau_i)(\gamma(m - 1) + 2) + \gamma mt_i}{(\gamma(n - 1) + 2)(2 - \gamma)} \quad (13)$$

As for the total consumption in a signatory  $i$ 's market from all varieties ( $Q_i^* = q_i^* + (m - 1)q_{ii}^* + (n - m)q_{ij}^*$ ), in the case of environmental cooperation scenario it is given by:

$$Q_i^* = \frac{n(a - c) - mt_i - t_j(n - m) - \tau_i(n - 1)}{\gamma(n - 1) + 2} \quad (14)$$

while in the case of trade cooperation and joint cooperation scenarios, it is given by:

$$Q_i^* = \frac{n(a - c) - mt_i - (t_j + \tau_i)(n - m)}{\gamma(n - 1) + 2} \quad (15)$$

We now look at non-signatories' markets where equilibrium quantities are the same irrespective of the scenario analysed.<sup>39</sup> The domestic firm  $j$ 's variety produced for its domestic market is given by:

$$q_j^* = \frac{(a - c)(2 - \gamma) - t_j(\gamma(m - 1) + 2) + \gamma mt_i + \gamma \tau_j(n - 1)}{(\gamma(n - 1) + 2)(2 - \gamma)} \quad (16)$$

while its variety produced for other non-signatories' markets is given by:

$$q_{jj}^* = \frac{(a - c)(2 - \gamma) - t_j(\gamma(m - 1) + 2) + \gamma mt_i - 2\tau_j}{(\gamma(n - 1) + 2)(2 - \gamma)} \quad (17)$$

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<sup>39</sup>The equilibrium emission taxes and trade tariffs themselves will of course be different depending on the scenario analysed given the different maximisation procedures.

and a signatory firm  $i$ 's variety produced for a non-signatory  $j$ 's market is given by:

$$q_{ji}^* = \frac{(a - c)(2 - \gamma) - t_i(\gamma(n - m - 1) + 2) + t_j(\gamma(n - m)) - 2\tau_j}{(\gamma(n - 1) + 2)(2 - \gamma)} \quad (18)$$

with the total consumption in a non-signatory  $j$ 's market from all varieties ( $Q_j^* = q_j^* + (n - m - 1)q_{jj}^* + mq_{ji}^*$ ) is given by:

$$Q_j^* = \frac{n(a - c) - mt_i - t_j(n - m) - \tau_j(n - 1)}{\gamma(n - 1) + 2} \quad (19)$$

We now look at the effects of emission taxes on firms' output.

### Proposition 1 - The Effects of Emission Taxes on Equilibrium Quantities

*The quantity of firm  $i$ 's ( $j$ 's) variety in any market decreases in signatories' (non-signatories') taxes,  $\frac{\partial q_i^*}{\partial t_i} < 0$ ,  $\frac{\partial q_{ii}^*}{\partial t_i} < 0$  and  $\frac{\partial q_{ji}^*}{\partial t_i} < 0$  ( $\frac{\partial q_j^*}{\partial t_j} < 0$ ,  $\frac{\partial q_{jj}^*}{\partial t_j} < 0$  and  $\frac{\partial q_{ij}^*}{\partial t_j} < 0$ ) irrespective of  $\gamma$ , and increases in non-signatories' (signatories') taxes,  $\frac{\partial q_i^*}{\partial t_j} > 0$ ,  $\frac{\partial q_{ii}^*}{\partial t_j} > 0$  and  $\frac{\partial q_{ji}^*}{\partial t_j} > 0$  ( $\frac{\partial q_j^*}{\partial t_i} > 0$ ,  $\frac{\partial q_{jj}^*}{\partial t_i} > 0$  and  $\frac{\partial q_{ij}^*}{\partial t_i} > 0$ ), except for  $\gamma = 0$  in which case  $\frac{\partial q_i^*}{\partial t_j} = 0$ ,  $\frac{\partial q_{ii}^*}{\partial t_j} = 0$  and  $\frac{\partial q_{ji}^*}{\partial t_j} = 0$  ( $\frac{\partial q_j^*}{\partial t_i} = 0$ ,  $\frac{\partial q_{jj}^*}{\partial t_i} = 0$  and  $\frac{\partial q_{ij}^*}{\partial t_i} = 0$ ). The total quantity consumed in any market decreases in signatories' and non-signatories taxes,  $\frac{\partial Q_i^*}{\partial t_i} < 0$ ,  $\frac{\partial Q_{ii}^*}{\partial t_i} < 0$ ,  $\frac{\partial Q_{ji}^*}{\partial t_i} < 0$ , and  $\frac{\partial Q_j^*}{\partial t_j} < 0$ , irrespective of  $\gamma$ .*

**Proof:** Follows directly from equations (9) to (19) above. **Q.E.D.**

Quantities of any firm's variety (signatory's or non-signatory's firm) produced for any individual market (signatories' and non-signatories' markets) are negatively affected by own taxes and positively affected by foreign taxes imposed on foreign counterparts. Only under full taste for variety (TFV), i.e.  $\gamma = 0$ , will a firm's output not benefit from a foreign tax imposed on a foreign firm. In which case, each firm acts as a monopolist in each market as consumers do not substitute between varieties and hence there is no competition among firms. As for total consumption in any market (signatory's or non-signatory's), it is always negatively affected by any tax (signatories' and non-signatories' taxes).

We now look at the effects of trade tariffs on firms' output. Given that trade tariffs affect only imports from foreign firms, we can draw the following intuitive conclusions, which can be verified from equations (9) to (19). The quantity of any firm's variety in any market is not affected by trade tariffs that operate in other markets. That is, in a signatory's market:  $\frac{\partial q_i^*}{\partial \tau_j} = 0$ ,  $\frac{\partial q_{ii}^*}{\partial \tau_j} = 0$  and  $\frac{\partial q_{ij}^*}{\partial \tau_j} = 0$ , and in a non-signatory's market:  $\frac{\partial q_j^*}{\partial \tau_i} = 0$ ,  $\frac{\partial q_{jj}^*}{\partial \tau_i} = 0$  and  $\frac{\partial q_{ji}^*}{\partial \tau_i} = 0$ . The same intuition also applies to total consumption in any market. That is, total consumption in a signatory's (non-signatory's) market



is not affected by non-signatories' (signatories') trade tariffs:  $\frac{\partial Q_i^*}{\partial \tau_j} = 0$  ( $\frac{\partial Q_j^*}{\partial \tau_i} = 0$ ). All these results hold true  $\forall \gamma$ . More formal conclusions are presented in Proposition 2 below.

**Proposition 2 - The Effects of Trade Tariffs on Equilibrium Quantities**

- *Under environmental cooperation scenario, the quantity of any signatory firm  $i$ 's variety produced for its own (any other signatory's or any non-signatory's) market increases (decreases) in the destination market's trade tariff,  $\frac{\partial q_i^*}{\partial \tau_i} > 0$  ( $\frac{\partial q_{ii}^*}{\partial \tau_i} < 0$ ,  $\frac{\partial q_{ji}^*}{\partial \tau_j} < 0$ , respec.), except for  $\gamma = 0$  in which case  $\frac{\partial q_i^*}{\partial \tau_i} = 0$  (irrespective of  $\gamma$ ). Under trade cooperation and joint cooperation scenarios:  $\frac{\partial q_{ii}^*}{\partial \tau_i} > 0$  and for  $\gamma = 0$ :  $\frac{\partial q_{ii}^*}{\partial \tau_i} = 0$ .*
- *Under all scenarios, the quantity of any non-signatory firm  $j$ 's variety produced for its own (any signatory's or other non-signatory's) market increases (decreases) in the destination market's trade tariff,  $\frac{\partial q_j^*}{\partial \tau_j} > 0$  ( $\frac{\partial q_{ij}^*}{\partial \tau_i} < 0$  or  $\frac{\partial q_{jj}^*}{\partial \tau_j} < 0$ , respec.), except for  $\gamma = 0$  in which case  $\frac{\partial q_j^*}{\partial \tau_j} = 0$  (irrespective of  $\gamma$ ).*
- *Under all scenarios, the total quantity consumed in any market decreases in the domestic trade tariff,  $\frac{\partial Q_i^*}{\partial \tau_i} < 0$  and  $\frac{\partial Q_j^*}{\partial \tau_j} < 0$ , irrespective of  $\gamma$ .*

**Proof:** Follows directly from equations (9) to (19) above. **Q.E.D.**

Under environmental cooperation scenario, the quantity of any firm's variety (signatory's or non-signatory's firm) produced for its domestic market is positively affected by the trade tariff that the domestic government imposes on imports from foreign firms. These tariffs provide the domestic firms with comparative advantage in the domestic market. Only under full taste for variety (TFV), i.e.  $\gamma = 0$ , will a firm not benefit from the trade tariff imposed on its competitors due to the independence of varieties. Exports of any firm's variety (signatory's or non-signatory's firm) to other markets (signatories' or non-signatories' markets) are negatively affected by the trade tariffs imposed by the domestic government in the destination markets. This holds true irrespective of consumers' taste for variety.

In the case of non-signatories' firms these results from the environmental cooperation scenario above can be extended to the other cooperation scenarios, namely trade cooperation and joint cooperation scenarios. Meanwhile, in the case of signatories' firms such interactions change when comparing the environmental cooperation scenario with the trade cooperation and joint cooperation scenarios. In the latter two scenarios trade tariffs are abolished within the coalition. Therefore, signatories firms' exports to other signatories' markets are not negatively affected by the domestic trade tariffs operating in those markets. On the contrary, they benefit from

them. In other words, the comparative advantage that signatories' firms enjoy in their domestic markets is now extended to other signatories' markets. Nevertheless, these positive effects disappear under the highest level of taste for variety (TFV),  $\gamma = 0$ .

Total consumption in any market (signatory's or non-signatory's) is always decreasing in the domestic trade tariff that operates in this market. Therefore, by extension, global consumption (or production) of all countries is always decreasing in any trade tariff.

One summarising conclusion for both Proposition 1 and Proposition 2 is that from firms' perspective the negative effects of taxes or tariffs always exist. Meanwhile, the positive effects of having counterparts facing tax or tariffs disappear under the highest level of taste for variety (TFV),  $\gamma = 0$ .

## 3.2 Second Stage

In this section, we derive equilibrium emission taxes and trade tariffs for signatories and non-signatories in the second stage. They follow from the F.O.Cs. for signatories' and non-signatories' welfare functions. Check Appendix 2 for the relevant equations. We find that the S.O.Cs. are satisfied.

Inserting equilibrium emission taxes and trade tariffs into equilibrium quantities reveals that we need to impose non-negativity constraints in order to ensure positive outputs. Essentially, these constraints boil down to requesting that the demand parameter  $a$  is larger than marginal production cost  $c$  plus a multiple of marginal damages. In other words, the demand parameter  $a$  must be large than certain threshold  $\underline{a}$ ,  $a > \underline{a}$ . The exact constraints are stated in Appendix 3, which are assumed to hold henceforth.

We will focus our analysis on two taste for varieties (TFV) cases for analytic tractability: no TFV with  $\gamma = 1$  and full TFV with  $\gamma = 0$ . Due to the complexity of the analytical results, despite assuming specific values on TFV, we resort to numerical simulations for the remainder of the paper. The parameters' constellations are as follows:  $n = 10$ ,  $m \leq n$ ,  $\gamma = \{0, 1\}$ ,  $\delta = \{10, 50, 100\}$ , and  $c = 0$ .<sup>40</sup>

We now look at signatories' and non-signatories' equilibrium trade tariffs and emission taxes in the three scenarios. It is expected that there will be a lot of interactions between both of these policy instruments. These interactions are a result of the fact that both instruments affect consumer surplus, producer surplus, taxes/tariffs revenues, as well as pollution damages. The main difference between the two instruments is that emission taxes target domestic production, whereas trade tariffs target imports, i.e. foreign production.

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<sup>40</sup>Since we have constant marginal costs symmetric across all firms (signatories' and non-signatories' ones) such simplification,  $c = 0$ , will not affect our qualitative results.

Therefore, before we present the results it is important to understand the incentives structure at play here. In setting these policies, the contesting incentives are: supporting domestic consumption (through lower emission taxes and/or trade tariffs), improving the competitiveness of the domestic producer (through lower emission taxes and/or higher trade tariffs on imports), generating tax/tariff revenues (through higher emission taxes and trade tariffs), and finally reducing damages (through higher emission taxes and trade tariffs). In short, these incentives can all be served using both policy instruments. Furthermore, these interactions are also shaped by the level of taste for variety (TFV), which defines the substitutability among varieties from consumers' perspective, the level of competition among producers and the spillovers of emission reductions among countries. Finally, these interactions are also influenced by the different maximisation procedures under each scenario.

In the next result we compare signatories' and non-signatories' emission taxes and trade tariffs across all three scenarios. For the purpose of distinguishing taxes and tariffs between scenarios, we use the superscript EC to indicate environmental cooperation (e.g.  $\tau_i^{EC}$  or  $t_i^{EC}$ ), TC to indicate trade cooperation (e.g.  $\tau_i^{TC}$  or  $t_i^{TC}$ ), and JC to indicate joint cooperation (e.g.  $\tau_i^{JC}$  or  $t_i^{JC}$ ).

### **Result 1 - Signatories' and Non-signatories' Equilibrium Emission Taxes and Trade Tariffs**

*Under the environmental cooperation scenario:*

- for  $\gamma = 1$ :  $t_i^{EC} > t_j^{EC} \forall m > 3$ , and  $\tau_i^{EC} > \tau_j^{EC} \forall m$ ,
- for  $\gamma = 0$ :  $t_i^{EC} > t_j^{EC} \forall m$ , and  $\tau_i^{EC} > \tau_j^{EC} \forall m$ .

*Under the trade cooperation scenario:*

- for  $\gamma = 1$ :  $t_i^{TC} > t_j^{TC} \forall m > 6$ , and  $\tau_i^{TC} < \tau_j^{TC} \forall m$ ,
- for  $\gamma = 0$ :  $t_i^{TC} > t_j^{TC} \forall m > 4$ , and  $\tau_i^{TC} > \tau_j^{TC} \forall m > 2$ .

*Under the joint cooperation scenario:*

- for  $\gamma = 1$ :  $t_i^{JC} > t_j^{JC} \forall m > 7$ , and  $\tau_i^{JC} < \tau_j^{JC} \forall m$ ,
- for  $\gamma = 0$ :  $t_i^{JC} > t_j^{JC} \forall m > 5$ , and  $\tau_i^{JC} > \tau_j^{JC} \forall m > 2$ .

Under the environmental cooperation scenario, we find that signatories' emission taxes are higher than non-signatories' ones under  $\gamma = \{0, 1\}$ , with the only exception for small coalitions when varieties are perfect substitutes (i.e.  $\gamma = 1$ ). In other words, signatories almost always impose higher emission taxes than non-signatories as

they internalise the damages externality for the whole coalition. There are two cases ( $m = \{2, 3\}$  under  $\gamma = 1$ ) where signatories' taxes are lower than non-signatories' ones. The rationale for this is as follows. When varieties are perfect substitutes, the positive spillovers of emission reductions' activities taking place in any country are high toward other countries given perfect substitution. In other words, signatories of these small coalitions ( $m = \{2, 3\}$ ) are fully benefiting from the emissions reduction efforts taking place in the large number of non-signatories' markets. As the coalition size increases,  $m > 3$ , signatories start to impose higher taxes than non-signatories. Such interactions however change when varieties are independent (i.e.  $\gamma = 0$ ) since reducing emissions from all varieties becomes equally important due to lower spillovers of benefits. Therefore, we find signatories' emission taxes are always higher than non-signatories' ones under  $\gamma = 0$ .

As for trade tariffs, signatories' tariffs are always higher than non-signatories' ones under the environmental cooperation scenario, irrespective of the taste for varieties (TFV) assumption (i.e.  $\gamma = \{0, 1\}$ ). Recall that under the environmental cooperation scenario, signatories do not abolish trade tariffs within the coalition. Therefore, they benefit from imposing high tariffs in three ways. First, they generate high tariffs revenues from all countries (other signatories and all non-signatories). Second, high tariffs provide domestic producers with comparative advantage in the domestic market (particularly under  $\gamma = 1$ , as we showed in Proposition 2). Finally, high trade tariffs lead to higher emission reductions from imports. As for domestic consumers, they are negatively affected by the high prices of domestic and foreign varieties. Nevertheless, the benefits of high revenues, strong comparative advantage for domestic producers and lower emissions outweigh the negative effects on domestic consumers.

Overall, under the environmental cooperation scenario it is clear that signatories are not only undertaking strong emission reductions activities within the coalition but also able to force emission reductions on imports by imposing high trade tariffs. In other words, providing signatories with an additional instrument such as trade tariffs might alter the incentives for free riding even if this additional policy instrument is used to maximise the welfare of each signatory individually.

We now move to the trade cooperation and joint cooperation scenarios. One of the key differences between these two scenarios and the previous one, apart from the maximisation procedure, is that trade tariffs are abolished within the coalition under these two scenarios. On the one hand, this implies that revenues from trade tariffs decline as the coalition size increases. On the other hand, accessing the tariff-free block will provide an additional incentive for cooperation. Furthermore, abolishing trade tariffs will lead to an inward shift of production and consumption within the coalition, which is particularly useful for consumers when varieties are perfect substitutes. We will discuss the results of both scenarios together as the intuition follows closely in both cases.

First we start with emission taxes. Under  $\gamma = 1$  we find signatories' taxes are always higher than non-signatories' ones for large coalition sizes only. This holds true in both

trade cooperation and joint cooperation scenarios. As mentioned earlier, given the perfect substitution of varieties signatories are fully benefiting from the spillovers of emission reductions efforts taking place in non-signatories' markets. However, as the coalition size increases, signatories start to impose higher taxes than non-signatories given the lower level of spillovers with fewer non-signatories. When varieties become independent (i.e.  $\gamma = 0$ ), reducing emissions from all varieties becomes equally important due to the lower spillovers and hence signatories start imposing higher emission taxes for medium to large coalition sizes.

As for trade tariffs, whenever varieties are perfect substitutes (i.e.  $\gamma = 1$ ) we find signatories' trade tariffs are always lower than non-signatories' ones. This holds true in both trade cooperation and joint cooperation scenarios. The reason for imposing lower trade tariffs is to support domestic consumption for the whole coalition given the joint welfare maximisation, which is a key difference between these two scenarios and the previous one. Although signatories' firms would benefit from higher tariff imposed on foreign imports as we showed in Proposition 1, they are still enjoying the access to tariff-free markets within the coalition. Such favorable terms of trade within the coalition result in an inward shift of production and consumption, and consequently higher profits for the coalition's firms within these markets. Furthermore, given the perfect substitution of varieties, signatories are fully benefiting from the spillovers of emissions reduction efforts taking place in non-signatories' markets whenever non-signatories' tariffs and/or taxes are higher. Such interactions however change when varieties are independent (i.e.  $\gamma = 0$ ) since reducing emissions from all varieties becomes equally important. That is, signatories also need to ensure that emissions from domestically consumed imports are also reduced. Therefore, whether signatories are cooperating on trade only or on both trade and climate change they impose higher trade tariffs than non-signatories  $\forall m > 2$ .

In summary, when varieties are independent (i.e.  $\gamma = 0$ ), signatories almost always impose higher taxes and tariffs than non-signatories as reducing emissions from all varieties is equally important. This holds true for all three scenarios. However, when varieties are perfect substitutes (i.e.  $\gamma = 1$ ) then the segmented market structure under each scenario plays an important role here. In the case of the environmental cooperation scenario, trade tariffs are not abolished within the coalition. Furthermore, they are imposed to maximise the individual welfare of each country only. This provides the incentive to impose high trade tariffs as the potential tariffs' revenues are high. Furthermore, signatories always impose higher emission taxes than non-signatories in order to internalise the damages' externality for the whole coalition. The negative effects of high taxes on consumers and producers are outweighed by the high revenues and lower damages. In the case of trade cooperation and joint cooperation scenarios under  $\gamma = 1$ , trade tariffs are abolished within the coalition. Furthermore, they are imposed to maximise the joint welfare of the whole coalition. Therefore, in choosing their trade tariffs signatories take into account the negative effects on all consumers within the coalition, rather than within their own country

only. This leads to lower trade tariffs in signatory markets than non-signatory ones. As for emission taxes, signatories' taxes are higher than non-signatories' ones for medium to large coalitions.

### 3.3 First Stage Results

In this section we will start by analysing the welfare properties, which will help us understanding the coalition's stability findings.

#### Result 2 - Game Properties

*Under the environmental cooperation scenario:*

- For  $\gamma = 1$ : the property of superadditivity and full cohesiveness hold, the externality property is positive for  $\forall m < 7$ , and a signatory's welfare is always higher than a non-signatory's one  $W_i - W_j > 0, \forall m$ .
- For  $\gamma = 0$ : the property of positive externality holds  $\forall m > 2$ , superadditivity fails  $\forall m = [3, 8]$ , full cohesiveness holds  $\forall m > 7$ , and a signatory's welfare is higher than a non-signatory's one  $W_i - W_j > 0, \forall m < 5$ .

*Under the trade cooperation scenario:*

- For  $\gamma = 1$ : the property of superadditivity holds  $\forall m > 5$ , externality is negative  $\forall m > 5$ , full cohesiveness holds, and a signatory's welfare is always higher than a non-signatory's one  $W_i - W_j > 0, \forall m$ .
- For  $\gamma = 0$ : the properties of superadditivity and negative externality hold, full cohesiveness fails  $\forall m > 3$ , and a signatory's welfare is always higher than a non-signatory's one  $W_i - W_j > 0, \forall m$ .

*Under the joint cooperation scenario:*

- For  $\gamma = 1$ : the property of superadditivity holds  $\forall m > 5$ , the externality property is negative  $\forall m > 6$ , full cohesiveness always holds, and a signatory's welfare is always higher than a non-signatory's one  $W_i - W_j > 0, \forall m$ .
- For  $\gamma = 0$ : the properties of superadditivity and negative externality hold, full cohesiveness fails  $\forall m = [4, 8]$ , and a signatory's welfare is always higher than a non-signatory's one  $W_i - W_j > 0, \forall m$ .

Forming and enlarging coalitions under the environmental cooperation scenario has the following implications on signatories' welfare under perfect substitution (i.e.  $\gamma = 1$ ). Since signatories impose high trade tariffs and emission taxes, they benefit from the high revenues as well as the high reductions in production and consumption emissions. Furthermore, despite the high emission taxes, signatories' firms benefit from the comparative advantage in their domestic market given that trade tariffs target all imports (from other signatories' firms as well as all non-signatories' ones). Meanwhile, signatories' consumers are negatively affected by the high prices of domestic and foreign varieties. However, given the perfect substitution of varieties, they can substitute the expensive imported varieties with the cheaper domestically produced one. In other words, there is an inward shift of consumption within each signatory's market individually. We find that the net effects of all these forces is positive, leading to the property of superadditivity to hold and hence providing strong incentives for cooperation.

As for non-signatories, on the one hand they benefit from the emission reductions activities undertaken by the coalition. On the other hand, their firms' exports profits suffer from the high tariffs operating in signatories' markets. For small coalitions, the positive effects of emission reductions outweigh the negative effects of the high tariffs imposed by the coalition leading to positive externalities. However, for large coalitions the negative effects of tariffs are much stronger and hence externalities become negative for these coalitions, in which case free riding is undermined. Overall, the incentives for forming coalitions under the environmental cooperation scenario with  $\gamma = 1$  are high leading to the stability of the grand coalition as we will show in the next result. Global welfare is always increasing with the coalition size given the benefits that signatories generate from joining the coalition and the high emission reductions activities. Finally, signatories' welfare is always higher than non-signatories' one given the high revenues from tariffs and taxes.

When varieties become independent (i.e.  $\gamma = 0$ ), superadditivity fails in most cases and hence the incentives to cooperate are undermined. The reasons for this are as follows. Firstly, signatories' firms do not benefit from the high tariffs imposed on their counterparts under  $\gamma = 0$ , as we showed in Proposition 2. Secondly, the high taxes and tariffs imposed by signatories have stronger negative effects on their consumers given the high taste for varieties ( $\gamma = 0$ ). As for the effects of environmental cooperation under  $\gamma = 0$  on non-signatories, we find that externalities are positive and hence the incentives to free ride are high. The reason externalities become positive under  $\gamma = 0$  is as follows. Generally, the externality from the coalition's emission reduction efforts is in principle always positive. However, the degree of these positive spillovers depend on the taste for variety (TFV). Under  $\gamma = 1$ , these positive spillovers can be undermined by non-signatories' reactions in the form of emission leakage due to the full substitutability of varieties. However, under  $\gamma = 0$  these positive spillovers can not be undermined by non-signatories' reactions due to varieties'

independence and hence the externality is always positive in this case.<sup>41</sup> Given these driving forces, the incentives for forming coalitions are low leading to the stability of small coalitions as we will show in the next result. As for full cohesiveness, it holds only for large coalitions given the high benefits from emission reductions for signatories as well as the positive externalities toward non-signatories and therefore global welfare increases with the coalition size for these large coalitions.

Forming and enlarging coalitions under the trade cooperation scenario has the following implications on signatories' welfare under perfect substitution (i.e.  $\gamma = 1$ ). Starting with the positive implications, signatories' consumers benefit from consuming tariffs-free varieties within the coalition which also face low emission taxes when the coalition size is small to medium. They also benefit from consuming the imports that face low trade tariffs. As for signatories' producers, they benefit from the trade tariffs imposed on non-signatories' imports and from accessing tariffs-free markets within the coalition as well as the low emission taxes, something that provides the incentives for an inward shift of production within the coalition. Looking at the negative implications of trade cooperation under perfect substitution (i.e.  $\gamma = 1$ ) on signatories, their governments tariffs' revenues are decreasing with the coalition size given that tariffs are abolished within the coalition. Meanwhile, signatories' production emissions are high and increasing with the coalition size given the low tariffs and taxes. We find that the benefit for consumers and producers outweigh the negative effects of low revenues and emission reductions whenever the coalition size is medium to large and therefore superadditivity holds, which illustrates the high incentives for forming large coalitions.

We now look at the welfare implications on non-signatories that result from forming and enlarging coalitions when signatories cooperate only on trade under perfect substitution (i.e.  $\gamma = 1$ ). Non-signatories' producers benefit from exporting to signatories' markets given the low trade tariffs (as oppose to other non-signatories' markets). As for non-signatories' consumers, they benefit from consuming imported signatories' varieties, which are cheaper than the varieties imported from other non-signatories' firms due to low emission taxes facing signatories' firms. However, as the coalition size increases these taxes increase (as we showed in Result 1) and hence non-signatories' consumers become worse off given that the majority of varieties become more expensive. As for non-signatories' governments, even though their tariffs are always higher than signatories' ones, they do not generate a lot of revenue for two reasons. Firstly, due to the inward shift of production within the coalition, for the reasons mentioned earlier. Secondly, non-signatories' firms also face better terms of trade in signatories' markets and hence they shift their exports more toward signatories' markets than non-signatories' ones (other than the domestic one). Furthermore, non-signatories also suffer from the increasing emissions generated by signatories' producers and consumers given the increasing access to tariff-free mar-

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<sup>41</sup>We showed similar effect in Al Khourdjie et al (2017), where the BTA regime exhibits positive externalities under  $\gamma = 0$  for the same rationale.



kets. The net effect of all these forces is negative for large coalitions and hence the externality property is negative, which discourages free riding under these coalition sizes.

These two properties combined help us understanding the net effects of coalition formation on global welfare, which is illustrated in the property of full cohesiveness. They also help us to understand the comparison of signatories' versus non-signatories' welfare. As for the full cohesiveness property, it always holds since for small to medium coalition sizes externalities are positive, while for large coalitions even though externalities become negative signatories benefit from cooperation. Global welfare is at the highest level at the grand coalition as we find that the cohesiveness property holds. As for the welfare comparison, signatories' welfare is always higher than non-signatories' one. Overall, it is evident that the incentives for forming coalitions when signatories cooperate on trade only are high under perfect substitution (i.e.  $\gamma = 1$ ), leading to the stability of the grand coalition as we will show in the next result.

The incentives for forming coalitions when signatories cooperate on trade only are also strong when varieties are independent (i.e.  $\gamma = 0$ ). As we discussed in Result 1, when varieties are independent it is important to reduce emissions from all varieties. This has led signatories to always impose high trade tariffs and emission taxes for almost all coalition sizes. While signatories' consumers are negatively affected by the high prices, their producers still benefit from the tariff-free access to markets within the coalition. As for signatories' governments they benefit from higher tariffs' and taxes' revenues as well as the higher emission reductions. The net effect of all these forces is positive and hence superadditivity holds, which illustrates the high incentives for forming coalitions. Looking at non-signatories, their producers (consumers) face higher tariffs (prices) for their exports (consumption) to signatories' markets (of signatories' varieties). Despite the fact that they benefit from higher emission reductions, the net effect of all these forces is negative and hence the externality property is negative, which undermines the incentives for free riding. Given these negative externalities and the strong benefits from joining the coalition, signatories' welfare is always higher than non-signatories' one. The net effects on global welfare is mostly negative as full cohesiveness fails due to the strong negative externalities. Overall, the incentives for forming coalitions when signatories cooperate on trade only are also high when varieties are independent (i.e.  $\gamma = 0$ ), leading to the stability of the grand coalition as we will show in the next result.

We now look at the third scenario where signatories cooperate on both trade and climate change. Under perfect substitution (i.e.  $\gamma = 1$ ) signatories impose lower trade tariffs than non-signatories, while their emission taxes become higher than non-signatories' one only for large coalitions given the joint welfare maximisation as we showed in Result 1. Therefore, signatories' consumers and producers increasingly benefit from the access to tariffs-free markets as the coalition size increases, and at the same time damages decrease for large coalition sizes given the higher taxes.

Put together, this lead to superadditivity to hold for medium to large coalitions and hence the incentives for cooperation are high. Meanwhile, incentives for free riding are undermined for medium to large coalition sizes as non-signatories face negative externalities. Even though non-signatories' firms benefit from the low-tariffs markets, their consumers suffer from the increase costs of signatories' varieties. Furthermore, the inward shift of production within the coalition means that non-signatories' government generate low tariffs' revenues. Therefore, for large coalitions these forces lead to net negative effects and hence negative externalities.

Looking at global welfare, it is not surprising that full cohesiveness always holds for this scenario given that for small to medium coalitions non-signatories enjoy the positive externalities, while for medium to large coalitions superadditivity holds. Finally, signatories' welfare is always higher than non-signatories' one given the increasing access to tariffs-free markets for their consumers and producers. Overall, the incentives for forming coalitions under this scenario are strong leading to the stability of the grand coalition.

Finally, we briefly look at the intuition of the properties' findings under the joint cooperation scenario for  $\gamma = 0$ , as it follows closely from the intuition of the trade cooperation scenario for  $\gamma = 0$ . Given that signatories impose higher tariffs and taxes, they generate higher revenues and enjoy lower level of damages leading to superadditivity to always hold. These high tariffs also mean that the negative effects on non-signatories' firms are high and hence externalities are always negative. The combination of these two properties explain why signatories' welfare is always higher than non-signatories' one. In terms of global welfare, full cohesiveness fails for medium to large coalitions given the negative externalities. Overall, the incentives for forming coalitions under this scenario are also strong, given that superadditivity holds and externalities are negative, leading to the stability of the grand coalition.

We now look at the coalition's stability results.

### **Result 3 - Coalition Stability**

*Let  $m^*$  denotes the size of an internally and externally stable coalition. If signatories cooperate on climate change only then  $m^* = n = 10$  for  $\gamma = 1$ , while  $m^* = 4$  for  $\gamma = 0$ . Meanwhile, if signatories cooperate on trade only or on both trade and climate change then  $m^* = n = 10$  for both  $\gamma = \{0, 1\}$ .*

Intuition for findings in this result follows closely from the findings and discussion in Result 2 above. When signatories cooperate on climate change only, the incentives for forming large coalitions under  $\gamma = 1$  are strong given that superadditivity always holds and externalities are negative for large coalition sizes. We showed in previous results that using high trade tariffs signatories can enforce emission reductions from imports and generate additional revenues at the same time. What is more, these high trade tariffs have led to negative externalities toward outsiders. Given these driving

forces, we find the grand coalition  $m^* = n = 10$  stable in equilibrium when varieties are perfect substitutes (i.e.  $\gamma = 1$ ). Essentially, what we have here is a design of a climate change agreement with two policy instruments emission taxes and trade tariffs. In order to form the climate change agreement, governments coordinate their emission taxes only. Having an additional policy instrument, such as trade tariffs imposed on all countries (signatories and non-signatories), provides an additional tool for signatories to discourage free riding.

Unfortunately, when varieties become independent (i.e.  $\gamma = 0$ ) the incentives for forming large coalitions breakdown. The key for such result is the lack of varieties' substitutability, which leads to the following. Firstly, signatories' consumers are more negatively affected by the high tariffs imposed on all imports given their high taste for variety / lack of varieties' substitutability under  $\gamma = 0$ . Secondly, signatories' firms do not benefit from the tariffs imposed on their counterparts as we showed in Proposition 2. Finally, externalities become positive as the spillovers from the coalition's emission reductions can not be undermined by non-signatories' reactions due to varieties' independence, and hence the externality is always positive in this case. All these driving forces led to a small stable coalition of  $m^* = 4$ .

We now compare these findings of the environmental cooperation scenario with those of Finus and Al Khourdjie (2017) as this paper is the closest paper in the literature to ours. The authors show that irrespective of consumers' taste for variety climate change coalitions always exhibit positive externalities toward non-signatories and hence incentives for free riding are strong. We show here that providing signatories with an additional instrument that could target foreign emissions such as trade tariffs might alter the incentives for free riding even if this additional policy instrument is used to maximise the welfare of each signatory individually. Unfortunately, these optimistic results only hold when varieties are perfect substitutes (i.e.  $\gamma = 1$ ) but not when they are independent (i.e.  $\gamma = 0$ ).

Cooperation on trade, such as forming customs' unions, is very attractive due to the exclusive benefits of free trade within the coalition as well as the in order to avoid the negative externalities of being outside the coalition. This intuition is shown by Yi (1996) who analyses customs' unions formation and stability under consumers' taste for variety. The author does not consider the environmental damages from production and trade. He finds that customs' unions always exhibit negative externalities toward non-signatories, while signatories always benefit from joining the coalition. Therefore, the grand coalition is stable. Essentially in this paper we benefit from his work and extend his model to include environmental damages as well as introduce emission taxes as a policy instrument. Signatories can either form a customs' union and coordinate their trade tariffs only, or form a joint customs' union and climate change agreement and coordinate both their trade tariffs and emission taxes. In both cases we find that the incentives for cooperation are also strong (inline with Yi, 1996). We find that the grand coalition is stable under both  $\gamma = \{0, 1\}$ . In other words, the strong cooperation incentive brought about by the customs' union also

carry over when the coalition considers environmental damages from production and coordinate its emission taxes.

### 3.4 Further Simulations

The results presented above hold for the non-negativity constraints. As explained in the introduction of the Second Stage section above, inserting equilibrium emission taxes and trade tariffs into equilibrium quantities reveals that we need to impose non-negativity constraints on parameter values in order to ensure positive outputs. Essentially, these constraints boil down to requesting that the demand parameter  $a$  is larger than marginal production cost  $c$  plus a multiple of marginal damages. In other words, the demand parameter  $a$  must be large than certain lower threshold  $\underline{a}$ ,  $a > \underline{a}$ . The exact constraints are stated in Appendix 3.

We conduct further simulations by increasing the demand parameter  $a$  above the non-negativity constraints to see whether our results hold for high levels of demand. Starting with the non-negativity constraints  $\underline{a}$  for both levels of taste for variety  $\gamma = \{0, 1\}$  for all three scenarios, we increase the level of demand using a scalar  $\lambda$  such that:  $\lambda \underline{a}$  for  $\lambda = \{2, 5, 10\}$ .<sup>42</sup>

Under the environmental cooperation scenario, we find the results presented above to hold for all levels of  $\lambda$ . In other words, our findings under the environmental cooperation scenario are robust. Under  $\gamma = 1$  there are strong incentives for cooperation leading to the grand coalition to always be stable. Meanwhile, under  $\gamma = 0$  the incentives for cooperation breakdown leading to the stability of small coalitions only.

Under the trade cooperation and joint cooperation scenarios, we find the results presented above to hold for all levels of  $\lambda$  only when taste for varieties are high (under  $\gamma = 0$ ). That is, our findings under these two scenarios are robust when  $\gamma = 0$ . Inline with the findings above, for all levels of  $\lambda$  externalities are negative and superadditivity holds providing strong incentives for cooperation and hence  $m^* = 10$ . The rationale for these findings follows from the discussion presented above.

Unfortunately, when consumers have no taste for varieties (i.e.  $\gamma = 1$ ) the incentives for cooperation break down and  $m^* = 1$  for both trade cooperation and joint cooperation scenarios. In driving the intuition for such findings we focus on the main driving forces for cooperation: the externality property and superadditivity. We find that as demand increases, negative externalities turn into positive in most cases making free riding more attractive. Meanwhile, superadditivity increasingly fails and hence leading to lower incentives for cooperation. Under high levels of demand all countries (signatories' and non-signatories') reduce their emission taxes as well as trade tariffs. Furthermore, signatories' taxes and tariffs become lower than those of

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<sup>42</sup> $\forall \lambda > 10$  the results do not change for all scenarios.

non-signatories in most cases, given the joint welfare maximisation.<sup>43</sup> On the one hand, non-signatories' consumers (producers) benefit from accessing the cheap varieties (markets), leading to positive externalities. On the other hand, signatories' governments generate less revenues while global emissions are increasing leading to lower incentives for cooperation.

## 4 Concluding Remarks

In an intra-industry trade model with horizontal products' differentiation and consumers' taste for variety (TFV) we studied the effects of issue linkage between climate change agreements and customs' unions. Our model essentially combines both models' setup from Finus and Al Khourdajie (2017) representing the climate change agreement and Yi (1996) representing customs' unions. In order to establish the issue linkage case we looked into three different scenarios of cooperation. Furthermore, we analysed how governments' policy and incentives to form coalitions change under each scenario. In checking for the size of stable coalitions we invoked the concept of internal and external stability.

Our model is an extension of Brander and Spencer (1985) framework where we assume *n ex ante* symmetric countries. Governments have two policy instruments. First, they can impose emission taxes on their domestic firm's production in order to reduce pollution damages. Second, they can impose trade tariffs on imports. Each government is concerned with the domestic firm's profit, revenues from emission taxes and trade tariffs, the utility of the domestic consumers and finally the environmental damages resulting from a global pollutant. Each firm produces a unique variety of a horizontally differentiated good and consumers have taste for these varieties (Yi, 1996).

We analyse three scenarios. The first is called environmental cooperation scenario, where signatories coordinate their climate policy and set their emission taxes collectively in order to maximise the joint welfare of the whole coalition. As for the trade policy, they neither coordinate their trade tariffs, nor abolish them within the coalition. The second scenario is called trade cooperation scenario, where signatories coordinate their trade tariffs only, i.e. cooperate on trade and form a customs' union, with no coordination of climate policy; emission taxes. The third scenario is called joint cooperation, which is essentially a combination of both previous scenarios illustrating the case of issue linkage. Signatories coordinate both their trade tariffs and emission taxes, i.e. forming a joint climate change and customs' union agreement. In

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<sup>43</sup>We do not find such interactions under the environmental cooperation scenario because signatories are maximising their own welfare only when they set their trade tariffs and hence they do not take into account the effects of high tariffs on other signatories' consumers. Furthermore, there are strong incentives to keep the tariffs high given that they can impose them on both other signatories' imports as well as non-signatories' ones.

all three scenarios non-signatories choose their own emission taxes and trade tariffs in order to maximise their individual welfare.

For analytic tractability, we focus on two cases of taste for varieties (TFV). The first is where consumers have no TFV and hence varieties are considered perfect substitutes. The second case is where taste for varieties is high and hence varieties are independent and consumers have a high preference for a diverse and balanced consumption bundle since varieties cannot be substituted at all.

Our results present new insights into environmental cooperation when governments are dealing with more than one issues, namely climate change and free trade in our context, and have two policy instruments to deal with them. In the case where consumers have no taste for varieties, i.e. varieties are perfect substitutes following the standard assumption in the literature, we find the incentives for cooperation on climate change are strong when countries coordinate their emission taxes even though they do not coordinate their trade policy. That is, providing signatories with an additional policy instrument, such as trade tariffs that can be imposed on all imports, makes them more powerful in the sense of having the ability to generate additional revenues as well as pose negative externalities toward non-signatories. These driving forces together lead to the stability of the grand coalition.

Unfortunately, when varieties become independent the incentives for forming large coalitions breakdown. The key for such result is the lack of varieties' substitutability, which leads to the following. Firstly, signatories' consumers are more negatively affected by the high tariffs imposed on all imports given their high taste for variety / lack of varieties' substitutability. Secondly, signatories' firms do not benefit from the tariffs imposed on their counterparts. Finally, externalities become positive as the spillovers from the coalition's emission reductions can not be undermined by non-signatories' reactions due to varieties' independence. In conclusion, the fact that signatories have an additional policy instrument does not help with the stability of large coalitions when varieties are independent. We find only small coalitions are stable in equilibrium.

Several studies in the literature show that cooperation on trade, such as forming customs' unions and free trade areas, is very attractive due to the exclusive benefits of free trade within the coalition as well as the in order to avoid the negative externalities of being outside the coalition, check Yi (1996 and 2000). In this paper, our trade cooperation scenario is essentially derived from this literature with the inclusion of environmental damages as well as the introduction of emission taxes as a policy instrument. Signatories in the trade cooperation scenario form a customs' union and coordinate their trade tariffs only. We find that the exclusive benefits of free trade and the negative externalities posed toward non-signatories are both providing the incentives for cooperation leading to the stability of the grand coalition irrespective of consumers' taste for variety. These driving forces also carry over when signatories form a joint agreement and coordinate both their emission taxes and trade tariffs leading to the grand coalition to be stable in equilibrium.

To our knowledge this is the first attempt to introduce the combination of issue linkage with customs' unions, horizontal products' differentiation and consumers' TFFV features to the literature of self-enforcing IEAs with trade. Future research avenues could be explored in terms of relaxing the symmetry assumption, and understanding the effect of ideal varieties or asymmetric consumers' TFFV between countries.

Finally, there are other trade policy instruments that could be employed to improve the incentives for cooperation on climate change. One of which is border tax adjustments (BTAs) analysed in Al Khourdajie et al (2017). Using this policy signatory governments can impose an additional border tax on imports from non-signatories' firms. This border tax amounts to the exact tax differential between the high emission tax that signatory firms are facing in their domestic markets and the low emission tax that non-signatory firms are facing for their exports to these markets. The authors show that when consumers have low or medium taste for varieties, BTAs lead to the stability of the grand coalition. Whereas, if consumers have a very high taste for varieties then only large coalitions are stable, but not the grand coalition.

The main differences between the BTA policy and trade tariffs are as follows. Firstly, BTAs are policy instruments available to signatory governments only. They are justified on the bases that only when signatories choose higher emission taxes than non-signatories they can impose BTAs on imports from non-signatories' firms. This will allow signatory governments to level the playing field in their own markets as well as create additional and explicit incentives to join the environmental agreement. As for trade tariffs, they are available to all governments of all countries, be it signatory or non-signatory ones. Tariffs in this context are employed as a trade policy instrument. They are widely adopted worldwide as part of the existing international trade system. In this paper, we explore whether signatory governments can benefit from existing policies to influence participation in climate change agreements. The second difference between BTAs and trade tariffs is as follows. BTAs are limited to the difference between signatories' emission taxes and non-signatories' one. Whereas, trade tariffs are not constrained to any rule. The level of signatories' tariffs is chosen to maximise their joint welfare. Indeed, it could also be the case the signatories' trade tariffs are lower than non-signatories' one as we showed in this paper.

Overall, combining the results of these two papers (Al Khourdajie et al, 2017, and Al Khourdajie, 2017) we can show that using trade tariffs in the context of joint cooperation on climate change and customs' unions achieve more superior results to using BTAs. Irrespective of the level of production differentiation and consumers' taste for variety, joint cooperation on climate change and trade always leads to the grand coalition to be stable in equilibrium. Whereas, in the case of BTAs the grand coalition is only stable when consumers have low or medium taste for varieties. If they have a very high taste for varieties then only large coalitions are stable, but not the grand coalition. The justification for such finding could be found in Al Khourdajie et al (2017).

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## 6 Appendixes

A detailed appendix of all derivations is available upon request. Below, we summarise the most important steps in the derivations in a compact form.

### 6.1 Appendix 1: Equilibrium Quantities Derivations

In this appendix we use the replacement functions method in order to derive the equilibrium quantities for all three scenarios. Given the segmented markets’ structure, quantities can be illustrated in the following table:

Segmented Markets	Signatory’s Firm	Non-signatory’s Firm	Total Consumption
Signatory’s Market	$q_i^*$ & $q_{ii}^*$	$q_{ij}^*$	$Q_i^*$
Non-signatory’s Market	$q_{ji}^*$	$q_j^*$ & $q_{jj}^*$	$Q_j^*$
Total Production	$Q_i^*$	$Q_{.j}^*$	$\sum_{k \in N} Q_k^*$

#### 6.1.1 Signatories’ Markets

In deriving the equilibrium quantities, we distinguish between the environmental cooperation scenario and the trade cooperation and joint cooperation scenarios.

##### 6.1.1.1 Environmental Cooperation Scenario

In a signatory’s market, there are three equilibrium quantities. The first  $q_i^*$  represents the domestic firm’s production for its own market.<sup>44</sup> This firm faces an emission tax

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<sup>44</sup>Notation: in  $q_i^*$  we used one sub-script only as the function represents domestic firm production for the domestic market.

only, imposed by its own government. The second equilibrium quantity  $q_{ii}^*$  represents other signatories firms' production to this signatory's market. In the case of the environmental cooperation scenario, these firms face an emission tax imposed by their own governments as well as a trade tariff imposed on their exports to this signatory's market. The third equilibrium quantity  $q_{ij}^*$  represents non-signatories firms' exports to this signatory's market. These firms face an emission tax imposed by their own governments as well as a trade tariff imposed on their exports to this signatory's market.

The profit of the domestic signatory's firm  $i$  in its domestic market  $i$  is given by  $\pi_i = q_i(p_i - c - t_i)$ . Substituting the inverse demand function from equation (3) above after the appropriate change in notation, we derive the following first order condition:

$$\frac{\partial \pi_i}{\partial q_i} = a - c - t_i - (2 - \gamma)q_i - \gamma Q_i = 0 \iff a - c - t_i - 2q_i - \gamma \sum_{l \in N \setminus \{i\}} q_{il} = 0 \quad (20)$$

where  $Q_i$  is the total quantity consumed in market  $i$  and  $\sum_{l \in N \setminus \{i\}} q_{il}$  is the sum of all consumed varieties by consumers in market  $i$  (first subscript) from all firms except the domestic firm  $i$  (second subscript). Equation (20) shows that the reaction functions ( $q_i = r_i(\sum_{l \in N \setminus \{i\}} q_{il})$ ) have a slope of  $-\gamma/2$ . Hence, the equilibrium is unique; the absolute value of the slope of the reaction function increases with the taste of variety parameter  $\gamma$ , and as  $\gamma$  approaches zero the strategic interaction among firms vanishes. Moreover, a necessary condition for positive quantities is  $a > c$ . Below, we will develop this non-negativity conditions further in order to ensure interior solutions.

The profit of any other signatories firms  $i$  (except the domestic one) in this domestic signatory market  $i$  is given by  $\pi_{ii} = q_{ii}(p_{ii} - c - t_i - \tau_i)$ . Notice that the difference between the domestic signatory's firm's profit function and other signatories' firms' profit functions is the trade tariff  $\tau_i$ . Substituting the inverse demand function from equation (3) above after the appropriate change in notation, we derive the following first order condition:

$$\frac{\partial \pi_{ii}}{\partial q_{ii}} = a - c - t_i - \tau_i - (2 - \gamma)q_{ii} - \gamma Q_i = 0 \iff a - c - t_i - \tau_i - 2q_{ii} - \gamma \sum_{l \in N, l \neq i} q_{il} = 0 \quad (21)$$

The profit of any non-signatory's firm  $j$  in market  $i$  is given by  $\pi_{ij} = q_{ij}(p_{ij} - c - t_j - \tau_i)$ . Substituting the inverse demand function from equation (3) above after the appropriate change in notation, we derive the following first order condition:

$$\frac{\partial \pi_{ij}}{\partial q_{ij}} = a - c - t_j - \tau_i - (2 - \gamma)q_{ij} - \gamma Q_i = 0 \iff a - c - t_j - \tau_i - 2q_{ij} - \gamma \sum_{l \in N, l \neq j} q_{il} = 0 \quad (22)$$

In order to derive the equilibrium quantities, we note that, as mentioned in the game setup above, in stage 2 the equilibrium emission taxes and trade tariffs are symmetric with all signatories choosing the same tax rate  $t_i$  as well as the same trade tariff  $\tau_i$ , and all non-signatories choosing the same tax rate  $t_j$  as well as the same trade tariff  $\tau_j$ , given symmetry. Furthermore, given our segmented market structure quantities produced for signatories' markets are the same; each signatory's firm produces the same output for its domestic market and the same output for all other signatories' markets, and each non-signatory's firm produces the same output for all signatories' markets.

Summing up all three first order conditions above after multiplying equation (21) by the number of all other signatories' firms except the domestic one ( $m - 1$ ) and equation (22) by the number of non-signatories ( $n - m$ ), we find the total quantity consumed in a signatory's market  $Q_i^*$  is given by:

$$Q_i^* = \frac{n(a - c) - mt_i - t_j(n - m) - \tau_i(n - 1)}{\gamma(n - 1) + 2} \quad (23)$$

Next we plug  $Q_i^*$  from (23) into (20) and solve for  $q_i$ , which is signatory firm  $i$ 's output for its domestic market:

$$q_i^* = \frac{(a - c)(2 - \gamma) - t_i(\gamma(n - m - 1) + 2) + \gamma t_j(n - m) + \gamma \tau_i(n - 1)}{(\gamma(n - 1) + 2)(2 - \gamma)} \quad (24)$$

Similarly, we plug  $Q_i^*$  from (23) into (21) and solve for  $q_{ii}$ , which is the output of other signatories firms  $i$ 's' (other than the domestic one) for this signatory  $i$ 's market:

$$q_{ii}^* = \frac{(a - c)(2 - \gamma) - t_i(\gamma(n - m - 1) + 2) + \gamma t_j(n - m) - 2\tau_i}{(\gamma(n - 1) + 2)(2 - \gamma)} \quad (25)$$

Finally, we plug  $Q_i^*$  from (23) into (22) and solve for  $q_{ij}$ , which is non-signatory firm  $j$ 's output for a signatory  $i$ 's market:

$$q_{ij}^* = \frac{(a - c)(2 - \gamma) - t_j(\gamma(m - 1) + 2) + \gamma m t_i - 2\tau_i}{(\gamma(n - 1) + 2)(2 - \gamma)} \quad (26)$$

### 6.1.1.2 Trade Cooperation and Joint Cooperation Scenarios:

In a signatory's market, there are three equilibrium quantities. The first  $q_i^*$  represents the domestic firm's production for its own market.<sup>45</sup> This firm faces an emission tax only, imposed by its own government. The second equilibrium quantity  $q_{ii}^*$  represents other signatories firms' production to this signatory's market. In the case of the trade cooperation and joint cooperation scenarios signatories abolish trade tariffs within

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<sup>45</sup>Notation: in  $q_i^*$  we used one sub-script only as the function represents domestic firm production for the domestic market.

the coalition and therefore these firms face an emission tax only, imposed by their own governments. In other words, under trade cooperation and joint cooperation scenarios  $q_i^* = q_{ii}^*$ . The third equilibrium quantity  $q_{ij}^*$  represents non-signatories firms' exports to this signatory's market. These firms face an emission tax imposed by their own governments as well as a trade tariff imposed on their exports to this signatory's market.

The profit of the domestic signatory's firm  $i$  in its domestic market  $i$  is given by  $\pi_i = q_i(p_i - c - t_i)$ . Substituting the inverse demand function from equation (3) above after the appropriate change in notation, we derive the following first order condition:

$$\frac{\partial \pi_i}{\partial q_i} = a - c - t_i - (2 - \gamma)q_i - \gamma Q_i = 0 \iff a - c - t_i - 2q_i - \gamma \sum_{l \in N \setminus \{i\}} q_{il} = 0 \quad (27)$$

The profit of any other signatories firms  $i$  (except the domestic one) in this domestic signatory market  $i$  is given by  $\pi_{ii} = q_{ii}(p_{ii} - c - t_i)$ . Notice that unlike the environmental cooperation scenario, in the trade cooperation and joint cooperation scenarios there are no differences between the domestic signatory's firm and other signatories' firms profit function when they produce for any signatory's market since trade tariffs are abolished within the coalition. Substituting the inverse demand function from equation (3) above after the appropriate change in notation, we derive the following first order condition:

$$\frac{\partial \pi_{ii}}{\partial q_{ii}} = a - c - t_i - (2 - \gamma)q_{ii} - \gamma Q_i = 0 \iff a - c - t_i - 2q_{ii} - \gamma \sum_{l \in N, l \neq i} q_{il} = 0 \quad (28)$$

The profit of any non-signatory's firm  $j$  in market  $i$  is given by  $\pi_{ij} = q_{ij}(p_{ij} - c - t_j - \tau_i)$ . Substituting the inverse demand function from equation (3) above after the appropriate change in notation, we derive the following first order condition:

$$\frac{\partial \pi_{ij}}{\partial q_{ij}} = a - c - t_j - \tau_i - (2 - \gamma)q_{ij} - \gamma Q_i = 0 \iff a - c - t_j - \tau_i - 2q_{ij} - \gamma \sum_{l \in N, l \neq j} q_{il} = 0 \quad (29)$$

Summing up all three first order conditions above after multiplying equation (28) by the number of all other signatories' firms except the domestic one ( $m - 1$ ) and equation (29) by the number of non-signatories ( $n - m$ ), we find the total quantity consumed in a signatory's market  $Q_i^*$  is given by:

$$Q_i^* = \frac{n(a - c) - mt_i - (t_j + \tau_i)(n - m)}{\gamma(n - 1) + 2} \quad (30)$$

Next we plug  $Q_i^*$  from (30) into (27) and solve for  $q_i$ , which is signatory firm  $i$ 's output for its domestic market:

$$q_i^* = \frac{(a - c)(2 - \gamma) - t_i(\gamma(n - m - 1) + 2) + \gamma(t_j + \tau_i)(n - m)}{(\gamma(n - 1) + 2)(2 - \gamma)} \quad (31)$$

Similarly, we plug  $Q_{ii}^*$  from (30) into (28) and solve for  $q_{ii}$ , which is the output of other signatories firms  $i$ 's (other than the domestic one) for this non-signatory  $i$ 's market:

$$q_{ii}^* = \frac{(a - c)(2 - \gamma) - t_i(\gamma(n - m - 1) + 2) + \gamma(t_j + \tau_i)(n - m)}{(\gamma(n - 1) + 2)(2 - \gamma)} \quad (32)$$

Equations (31) and (32) illustrate why  $q_i^* = q_{ii}^*$  under the trade cooperation and joint cooperation scenarios.

Similarly, we plug  $Q_{ii}^*$  from (30) into (29) and solve for  $q_{ij}$ , which is non-signatory firm  $j$ 's output for a signatory  $i$ 's market:

$$q_{ij}^* = \frac{(a - c)(2 - \gamma) - (t_j + \tau_i)(\gamma(m - 1) + 2) + \gamma m t_i}{(\gamma(n - 1) + 2)(2 - \gamma)} \quad (33)$$

### 6.1.2 Non-signatories' Markets

In a non-signatory's market, there are always three equilibrium quantities which are the same irrespective of the scenario analysed.<sup>46</sup> The first  $q_j^*$  represents the domestic firm's production for its own market.<sup>47</sup> This firm faces an emission tax only, imposed by its own government. The second equilibrium quantity  $q_{jj}^*$  represents other non-signatories firms' exports to this non-signatory's market. These firms face an emission tax imposed by their own governments as well as a trade tariff imposed on their exports to this non-signatory's market. Finally, the third equilibrium quantity  $q_{ji}^*$  represents signatories firms' exports to this non-signatory's market. These firms face an emission tax imposed by their own governments as well as a trade tariff imposed on their exports to this non-signatory's market.

The profit of the domestic non-signatory's firm  $j$  in its domestic market  $j$  is given by  $\pi_j = q_j(p_j - c - t_j)$ . Substituting the inverse demand function from equation (3) above after the appropriate change in notation, we derive the following first order condition:

$$\frac{\partial \pi_j}{\partial q_j} = a - c - t_j - (2 - \gamma)q_j - \gamma Q_j = 0 \iff a - c - t_j - 2q_j - \gamma \sum_{l \in N \setminus \{j\}} q_{jl} = 0 \quad (34)$$

The profit of any other non-signatory's firm  $j$  (except the domestic one) in this domestic non-signatory's market  $j$  is given by  $\pi_{jj} = q_{jj}(p_{jj} - c - t_j - \tau_j)$ . Substituting

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<sup>46</sup>The emission taxes and trade tariffs themselves will of course be different depending on the scenario analysed given the different maximisation procedures.

<sup>47</sup>Notation: in  $q_j^*$  we used one sub-script only as the function represents domestic firm production for the domestic market.

the inverse demand function from equation (3) above after the appropriate change in notation, we derive the following first order condition:

$$\frac{\partial \pi_{jj}}{\partial q_{jj}} = a - c - t_j - \tau_j - (2 - \gamma)q_{jj} - \gamma Q_j = 0 \iff a - c - t_j - \tau_j - 2q_{jj} - \gamma \sum_{l \in N, l \neq j} q_{jl} = 0 \quad (35)$$

The profit of a signatory's firm  $i$  in a non-signatory's market  $j$  is given by  $\pi_{ji} = q_{ji}(p_{ji} - c - t_i - \tau_j)$ . Substituting the inverse demand function from equation (3) above after the appropriate change in notation, we derive the following first order condition:

$$\frac{\partial \pi_{ji}}{\partial q_{ji}} = a - c - t_i - \tau_j - (2 - \gamma)q_{ji} - \gamma Q_j = 0 \iff a - c - t_i - \tau_j - 2q_{ji} - \gamma \sum_{l \in N, l \neq i} q_{jl} = 0 \quad (36)$$

Summing up all three first order conditions above after multiplying equation (35) by the number of all other non-signatories' firms except the domestic one ( $n - m - 1$ ) and equation (36) by the number of signatories ( $m$ ), we find the total quantity consumed in a non-signatory's market  $Q_j^*$  is given by:

$$Q_j^* = \frac{n(a - c) - mt_i - t_j(n - m) - \tau_j(n - 1)}{\gamma(n - 1) + 2} \quad (37)$$

Next we plug  $Q_j^*$  from (37) into (34) and solve for  $q_j$ , which is non-signatory firm  $j$ 's output for its domestic market:

$$q_j^* = \frac{(a - c)(2 - \gamma) - t_j(\gamma(m - 1) + 2) + \gamma mt_i + \gamma \tau_j(n - 1)}{(\gamma(n - 1) + 2)(2 - \gamma)} \quad (38)$$

Similarly, we plug  $Q_j^*$  from (37) into (35) and solve for  $q_{jj}$ , which is the output of other non-signatories' firms  $j$ 's (other than the domestic one) for this non-signatory  $j$ 's market:

$$q_{jj}^* = \frac{(a - c)(2 - \gamma) - t_j(\gamma(m - 1) + 2) + \gamma mt_i - 2\tau_j}{(\gamma(n - 1) + 2)(2 - \gamma)} \quad (39)$$

Finally, we plug  $Q_j^*$  from (37) into (36) and solve for  $q_{ji}$ , which is a signatory firm  $i$ 's output for any non-signatory  $j$ 's market:

$$q_{ji}^* = \frac{(a - c)(2 - \gamma) - t_i(\gamma(n - m - 1) + 2) + t_j(\gamma(n - m)) - 2\tau_j}{(\gamma(n - 1) + 2)(2 - \gamma)} \quad (40)$$

## 6.2 Appendix 2: Equilibrium Emission Taxes and Trade Tariffs

Due to the size of these equations, they can be provided in separate PDF files upon request.

## 6.3 Appendix 3: Non-negativity Constraints

Inserting equilibrium emission taxes and trade tariffs into equilibrium quantities reveals that we need to impose non-negativity constraints in order to ensure positive outputs. These constraints depend on the scenario considered. Essentially, they boil down to requesting that the demand parameter  $a$  is larger than marginal production cost  $c$  plus a multiple of marginal damages. These constraints are established analytically but due to the complexity of the results we resort to numerical simulations. The parameters' constellations are as follows:  $n = 10$ ,  $m \leq n$ ,  $\gamma = \{0, 1\}$ ,  $\delta = \{10, 50, 100\}$ , and  $c = 0$ .<sup>48</sup>

### 6.3.1 Environmental Cooperation scenario

For the environmental cooperation scenario, we establish the non-negativity constraints numerically requesting that the demand parameter  $a$  is larger than a certain threshold, i.e. larger than a lower threshold  $\underline{a}$ . In order to establish the non-negativity constraints for  $\gamma = \{0, 1\}$ , we look for the most restrictive  $\underline{a}$  (i.e. for all  $m$  under each quantity) and find the following:

$\underline{a}$	$\gamma = 1$	$\gamma = 0$
$q_i^*$	$c + 25\delta$	$c + 10\delta$
$q_{ii}^*$	$c + 10\delta$	$c + 10\delta$
$q_{ij}^*$	$c + 55\delta$	$c + 10\delta$
$q_j^*$	$c + 15\delta$	$c + 10\delta$
$q_{jj}^*$	$c + 28\delta$	$c + 10\delta$
$q_{ji}^*$	$c + 10\delta$	$c + 10\delta$

Therefore, the most restrictive non-negativity constraint for  $\gamma = \begin{cases} 1 & \underline{a} = c + 60\delta \\ 0 & \underline{a} = c + 15\delta \end{cases}$ .

### 6.3.2 Trade Cooperation scenario

Similarly for the trade cooperation scenario, in order to establish the non-negativity constraints for  $\gamma = \{0, 1\}$ , we look for the most restrictive  $\underline{a}$  (i.e. for all  $m$  under each quantity) and find the following:

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<sup>48</sup>Since we have constant marginal costs symmetric across all firms (signatories' and non-signatories' ones) such simplification,  $c = 0$ , will not affect our qualitative results.



$\underline{a}$	$\gamma = 1$	$\gamma = 0$
$q_i^* \ \& \ q_{ii}^*$	$c + 10\delta$	$c + 10\delta$
$q_{ij}^*$	$c + 118\delta$	$c + 10\delta$
$q_j^*$	$c + 50\delta$	$c + 10\delta$
$q_{jj}^*$	$c + 175\delta$	$c + 10\delta$
$q_{ji}^*$	$c + 40\delta$	$c + 11\delta$

Therefore, the most restrictive non-negativity constraint for  $\gamma = \begin{cases} 1 & \underline{a} = c + 180\delta \\ 0 & \underline{a} = c + 15\delta \end{cases}$ .

### 6.3.3 Joint Cooperation scenario

Similarly for the trade cooperation scenario, in order to establish the non-negativity constraints for  $\gamma = \{0, 1\}$ , we look for the most restrictive  $\underline{a}$  (i.e. for all  $m$  under each quantity) and find the following:

$\underline{a}$	$\gamma = 1$	$\gamma = 0$
$q_i^* \ \& \ q_{ii}^*$	$c + 10\delta$	$c + 10\delta$
$q_{ij}^*$	$c + 118\delta$	$c + 10\delta$
$q_j^*$	$c + 42\delta$	$c + 10\delta$
$q_{jj}^*$	$c + 138\delta$	$c + 10\delta$
$q_{ji}^*$	$c + 28\delta$	$c + 10\delta$

Therefore, the most restrictive non-negativity constraint for  $\gamma = \begin{cases} 1 & \underline{a} = c + 150\delta \\ 0 & \underline{a} = c + 15\delta \end{cases}$ .

Under cross-scenario analyses, we assume the most restrictive constraint among the three scenarios to hold.

## 6.4 Appendix 4: First Stage Results

Due to the size of these equations, they can be provided in separate PDF files upon request.



## Part VIII

# Summary of Conclusions

In this thesis, we studied the formation and stability of various designs of climate change agreements. Our model is an extension of Brander and Spencer (1985) Cournot oligopoly framework where we assume *n ex ante* symmetric countries. Governments are concerned not only with their firms' profit and tax revenues but also with the utility of their consumers and environmental damages resulting from a global pollutant. We introduced two new features to the literature. Firstly, firms produce a horizontally differentiated good, i.e. the same good but in different varieties where each firm produces one unique variety. Secondly, consumers can have various degrees of taste for the varieties of this good. For analytical tractability, in most parts of the thesis we focused on three cases of TFV. Firstly, the case of "no TFV" under which varieties are perfect substitutes. Secondly, the case of "partial TFV" that implies some degree of substitutability among varieties. Thirdly, the case of "full TFV" (or maximum TFV) under which consumers have high preference for a balanced consumption bundle and varieties are independent. Stability of a coalition leading to an agreement was tested by invoking the concept of internally and externally stable cartels. We also check for coalition stability under exclusive membership where appropriate.

We demonstrated that the formation of climate change agreements is globally beneficial. Global welfare increases with the size of agreements and obtains its maximum if the grand coalition forms. However, the grand coalition or even smaller coalitions may not be stable because of two reasons. Firstly, the benefits from policy coordination are non-exclusive, a features which we related to the property of positive externality of coalition formation. Secondly, the gains from cooperation for those involved in enlarging coalitions may be small or even negative.

We showed that for the "no TFV" scenario, signatories of an agreement increase their taxes with the size of the agreement. Signatory governments have an incentive to internalise two negative externalities, both associated with high quantities. A reduction of output stabilises the price in the output cartel and also reduces environmental damages. Non-signatories free-ride on signatories' efforts and lower their taxes. Hence, taxes are strategic substitutes between signatories and non-signatories. In our model, this meant that no agreement was stable. In contrast, for the "full TFV" scenario, foreign taxes have no effect on domestic firms' output. In the context of an agreement, this implies that taxes of signatories (non-signatories) have no effect on the output of non-signatories' (signatories') firms. We found that this implies that taxes between signatories and non-signatories become strategically independent. Regardless whether signatories increase or decrease their tax with the size of the agreement, non-signatories' equilibrium taxes do not change. This reduces the free-rider incentive, but it remains positive, which explains that this led only to

small stable coalitions.

In the second paper, we extended the previous paper by providing the climate change agreement's signatories with an additional policy instrument called border tax adjustment (BTA). Using this policy signatory governments can impose an additional border tax on imports from non-signatories' firms. This border tax amounts to the tax differential between the high emission taxes that signatory firms are facing in their domestic markets and the low emission taxes that non-signatory firms are facing for their exports to these markets. In this setup we examined the effects of border tax adjustments in influencing countries' decisions on their emission taxes as well as membership status by comparing two cases: climate agreements with and without border tax adjustments, BTA and No BTA regimes, respectively.

We find that introducing BTAs under "no TFV" or "partial TFV" enhances the incentives to join the coalition as signatories generate additional tax revenues given the BTA policy. Furthermore, BTAs undermine the free riding incentives as the coalition exhibits negative externalities toward non-signatories. Under internal and external stability, these driving forces together led to the grand coalition to be stable in equilibrium. When the exclusive membership rule is considered, we found medium-sized coalitions to be stable in equilibrium, as signatories of these coalitions are enjoying the additional tax revenues they are generating through the BTAs and hence they do not allow all countries to join the coalition.

Looking at the full TFV case, introducing BTAs doesn't lead to negative externalities against non-signatories anymore. In other words, each non-signatory benefits from signatories' efforts. These benefits outweigh the negative effects of the BTAs, leading to positive externalities. Nevertheless, given the additional BTA revenue that signatories enjoy, countries always have the incentives to join the coalition and hence large coalitions are stable.

In the third paper we studied the formation of joint climate change and customs' union agreements. Governments have two policy instruments. First, they can impose emission taxes on their domestic firm's production in order to reduce pollution damages. Second, they can impose trade tariffs on imports. We analyse three scenarios. The first is called environmental cooperation scenario, where signatories coordinate their climate policy and set their emission taxes collectively in order to maximise the joint welfare of the whole coalition. As for the trade policy, they neither coordinate their trade tariffs, nor abolish them within the coalition. The second scenario is called trade cooperation scenario, where signatories coordinate their trade tariffs only, i.e. cooperate on trade and form a customs' union, with no coordination of climate policy; emission taxes. In this scenario, signatories abolish trade tariffs within the coalition and impose tariffs on imports from non-signatories to maximise the joint welfare of the coalition. As for the climate policy, each signatory chooses an emissions tax that maximises its own welfare. The third scenario is called joint cooperation, which is essentially a combination of both previous scenarios illustrating the case of issue linkage. Signatories coordinate both their trade tariffs and emission

taxes, i.e. forming a joint climate change and customs' union agreement. In this scenario, signatories abolish trade tariffs within the coalition and impose tariffs on imports from non-signatories to maximise the joint welfare of the coalition. They also jointly choose a uniform emission tax that maximises the joint welfare of the coalition. In all three scenarios non-signatories choose their own emission taxes and trade tariffs in order to maximise their individual welfare.

Our results present new insights into environmental cooperation when governments are dealing with more than one issues, namely climate change and free trade in our context, and have two policy instruments to deal with them. In the case where consumers have no taste for varieties, i.e. varieties are perfect substitutes following the standard assumption in the literature, we find the incentives for cooperation on climate change are strong when countries coordinate their emission taxes even though they do not coordinate their trade policy. That is, providing signatories with an additional policy instrument, such as trade tariffs that can be imposed on all imports, makes them more powerful in the sense of having the ability to generate additional revenues as well as pose negative externalities toward non-signatories. These driving forces together lead to the stability of the grand coalition. Unfortunately, when varieties become independent the incentives for forming large coalitions breakdown. The fact that signatories have an additional policy instrument does not help with the stability of large coalitions when varieties are independent and we find only small coalitions are stable in equilibrium. A more detailed discussion on these findings is presented later in the paper.

As for the trade cooperation scenario, we find that the exclusive benefits of free trade and the negative externalities posed toward non-signatories are both providing the incentives for cooperation leading to the stability of the grand coalition irrespective of consumers' taste for variety. These driving forces also carry over when signatories form a joint agreement and coordinate both their emission taxes and trade tariffs leading to the grand coalition to be stable in equilibrium. In relating these results to the current literature, while the incentives for forming climate change coalitions are not strong enough due to positive externalities (Finus and Al Khourdajie, 2017), the incentives for forming customs' unions are stronger given the benefits of joining the coalition and the incentives to avoid negative externalities (Yi, 1996). In our environmental cooperation scenario we show that providing signatories with additional policy instrument might sometimes lead to strong incentive for cooperation. As for our joint cooperation scenario, we show that the joint agreement combines both features of strong incentives for cooperation brought about by the customs' unions as well as the policy instrument to deal with the damages' externality.

To our knowledge, this is the first attempt to introduce horizontal products' differentiation and consumers' taste for variety to the literature of international environmental agreements. In this setting, it is also the first attempt to analyse the effects of instrumenting climate change agreement with border tax adjustment, and the effects of issue linkage with trade agreements. Our stylized model allows for exploring future

research avenues in relaxing the symmetry assumption and further investigations of sub-features of TFV, such as ideal varieties or asymmetric consumers' TFV between countries. Future research could be explored in terms of introducing an additional policy instruments for non-signatories such as tax rebates that allow them to mitigate the BTAs negative effects on their firms' profit when they export to signatories' markets.